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Dedicated to my beloved parents

Ana Bonaventura
&
Theofil Mnuka

**STUDIES IN THE BOLLWORM, HELIOTHIS ARMIGERA HUBNER,
THE KEY COTTON PEST IN TANZANIA, AS A BASIS FOR
IMPROVED INTEGRATED PEST MANAGEMENT**

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Abstract

Heliothis armigera, the cotton bollworm, is an important cotton pest in Tanzania and also attacks some food crops grown in the cotton areas.

A study was done in cropping systems practised by small scale farmers in Western Tanzania. The objective was to examine the bionomics of the pest in this agro-ecosystem with emphasis on improved integrated control strategies.

The level and timing of H. armigera infestations were studied on maize, sorghum, cotton, chickpea, tomatoes and Cleome sp. The attractive stages of these crops provide overlapping hosts throughout the year. Chickpea and tomato production during the dry season in the study area has enabled the pest and its natural enemies to survive the dry season, this bridging an otherwise unfavourable period.

Larval mortalities were assessed on its different hosts. Adequate rainfall favoured the build up of the pest whereas dry weather caused drastic population decline. Larval diseases and parasitism were important but neither prevented the pest population from causing economic damage to the cotton crop.

Prospects for forecasting pest attack on cotton from infestations on other hosts, notably maize, showed that the greatest benefit is in predicting the timing of the early infestations.

Light and pheromone traps for monitoring and forecasting H. armigera infestations were evaluated. A suitable pheromone trap for use in Tanzania was identified. Overall, the pheromone traps provided a better estimate than light traps of the subsequent level of infestation and damage on cotton.

A calendar spraying programme gave higher yields of seed cotton and greater economic returns than by using damage thresholds. The chosen thresholds, in retrospect, proved too high or too low to trigger optimal spraying and therefore more work is required before an appraisal can be made of their value.

The implications of the research results are discussed and future research needs in Western Tanzania are proposed.

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INTRODUCTION

1.1 Background to the study

Cotton in Tanzania is produced mostly by the small scale farmer as a cash crop. The crop is usually farmed with other crops such as maize, sorghum, millets, sunflower, beans and groundnuts all of which are rainfed. In this system of farming, farmers intercrop (mixed cropping) a range of food crops which can be sown before or simultaneously with the cotton crop, but cotton is sown mostly as a monocrop.

Cotton is grown as an export crop to earn foreign currency. Nationally, cotton is next to coffee, the second most important export crop and earns Tanzania 10-15 per cent of the foreign exchange. Consequently, much research effort is directed into methods to increase both the quality and quantity of the crop in the country.

1.2 The farming system and the economic significance of cotton and other relevant crops in the Western Cotton Growing Area (WCGA)

The main cropping season begins in October at the start of the short rains and ends in September at the end of the dry season. This 12-months agricultural year was used throughout in the study of the bionomics of H. armigera.

The sowing of maize, sorghum, millets, grain legumes, sweet potato and cassava begins with the onset of the short rains and

continues up to mid-February. Maize, sorghum and millet are often intercropped with either beans, groundnuts, cowpeas, greengram or bambaranuts. Sequential maize sowing continues up to mid-February. Cotton is sown between the last week of November and the end of December.

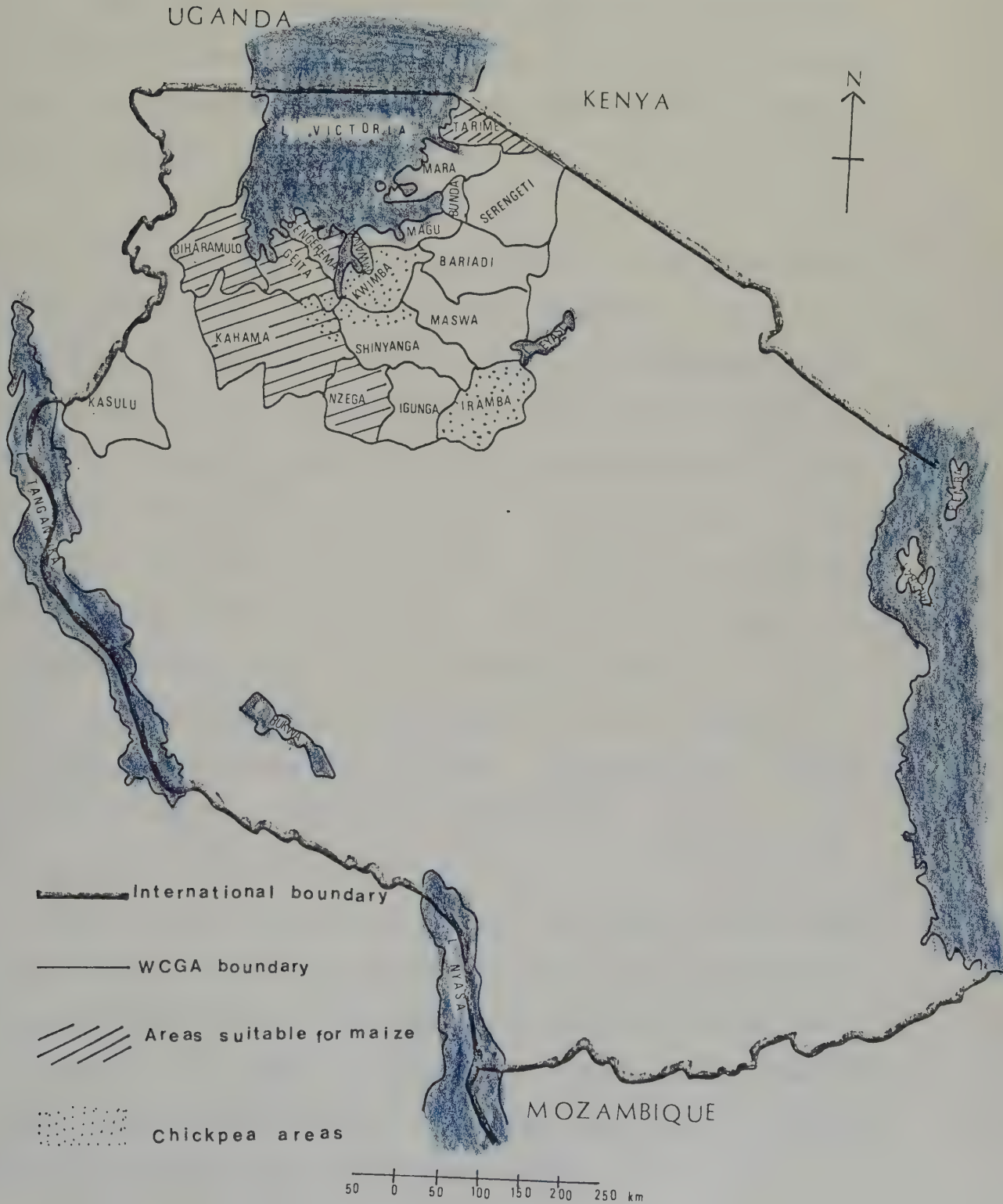
As the main rains decline in May, chickpea is sown on the 'mbuga' soils (heavy clay soils) whereas vegetables, especially tomatoes are planted throughout the year in backyard gardens. Tomato production is gaining popularity in the Mwanza region as a 'cash' crop especially in Magu-Kayenze, Sengerema, Kwimba, Geita and Ukerewe districts. Tomatoes are also gaining importance in Nzega district, Tabora region (Fig. 1).

1.2.1 Cotton

Cotton is the main cash crop in Western Tanzania which produces about 90 per cent of the cotton produced in the country most of which is grown on the southern shores of Lake Victoria (Fig. 1). Much of the crop is grown on the light hillsand soils with a smaller proportion on the mbuga soils. Although it is still a small holder crop, there has been a recent government move to encourage large scale communal (Ujamaa) and block farms many of which vary from 50ha to well over 100ha in size. Under the ujamaa cotton farming system the cotton hectareage is communially owned and all the field operations are centrally organized and implemented by the villagers. In contrast, in block farms, each farmer owns one to two acres of cotton in the cotton block area but each individual farmer is independent and the field operations are not coordinated.

Fig 1

The western cotton growing area of Tanzania showing areas suitable for maize growing



1.2.2 Maize

Excepting areas of North Mara Highlands (Tarime), parts of Kagera region, Geita, Sengerema and Kahama districts (Fig. 1) the conditions in the WCGA are generally not suitable for maize production due to poor soils and mid-season droughts in January and February. Despite these natural limitations, preference for maize as a staple food over other grains continues to increase.

Traditionally, sorghum and millet constituted the staple grains in much of western Tanzania. By 1934, maize was still of minor importance and was consumed on the cob only (Richardson, 1934). However, over the years, maize has gradually replaced the traditional grains for a number of reasons. French (1948) observed that a change in social conditions coupled with better nutritional value of maize has led to many people eating more maize. The move from sorghum and millet was also accelerated by losses incurred from bird damage (Peat and Brown, 1963). More recently, shortage of maize on the local market together with high black-market prices has resulted in an increase in the acreage of maize and a decline in the area of alternative food crops (Akonaay and Mazige, 1982).

Maize crops in the WCGA have few disease and pest problems apart from streak virus and stalk borer, and more recently, Prostephanus truncatus which is now a late season and storage pest, all of which can greatly reduce yield. H. armigera is a minor pest of maize in Tanzania since the cultivars grown have tight ears which do not allow easy penetration of the cob by the pest larvae.

The maize varieties recommended in Western Tanzania are Katumani, Ukiriguru Composite A (UCA) and more recently, Kilima. Katumani and Kilima are short maturing and suitable for most areas of Western Tanzania but Katumani has a low yield potential and no stress tolerance. The short maturing varieties flower in about 45 days and are ready for harvest in 90 days, and hence their popularity. These varieties are often sown with the short rains in October and begin flowering in mid-December.

UCA on the other hand, is long maturing and flowers about 75 days after sowing. However, this variety is only suitable for areas with high reliable rainfall. This variety is sown at the end of December to mid January and flowers in April-May.

Overall, there is sequential maize sowing from October to mid February.

1.2.3 Sorghum

Sorghum, is the traditional staple grain over much of Western Tanzania (Richardson, 1934; Thornton, 1938). It was the main food crop on the heavier soils (Peat and Prentice, 1946) where it was intercropped with legumes.

Sorghum grain yield can be seriously reduced in some years by stalk borers, shoofly, birds (Quelea quelea spp) and the semi-parasitic weed, Striga spp. (Peat and Prentice, 1946; Doggett, 1953). In some years losses due to H. armigera can be very high

especially on varieties with compact heads (Peat, et al; 1954; Doggett, 1964).

Despite increasing unpopularity of sorghum among farmers in recent years, the Government is trying to emphasize the importance of the crop over much of WCGA especially in the marginal areas where maize gives only a meagre crop. In the marginal areas, sorghum is therefore a more suitable crop since it is drought tolerant. The recommended varieties, serena (red type) and lulu (white type) are short maturing and compact head. Both flower 45 days after sowing and should be ready for harvest in about 90 days. In addition, traditional long maturity open head cultivars are still grown in some areas, especially in the southern cotton variety zone.

1.2.4 Chickpea

Chickpea is grown on the mbuga soils where it can be planted late in the season and flourish well with little rainfall. It is usually planted in May, though somewhat earlier sowing is preferable if rains are light (Glegg, 1947). Land preparation for the crop can be done at a slack time and therefore does not compete much for labour with other crops.

Chickpea in Western Tanzania is recorded as having been grown since 1932 for sale to Indians in Mwanza and Kwimba districts but remained of minor importance until 1943 when it became an important economic crop (Glegg, 1947). Since 1943, it has been produced as a cash crop over much of WCGA especially in the Lake Province (Peat and

Prentice, 1946; Rounce, 1947; Biggs, 1952). The crop is of great value especially in a dry season when most legumes fail. Glegg (1947) commented that chickpea was of greater value than groundnuts and comparable in value to paddy in a dry season. In 1945, Rounce (1946) noted that Bulima and Msalala in Mwanza district were the main producing areas. However, by 1949, the crop had spread to many new areas including Isanga Basin at the south end of Smith Sound. Between 1943 and 1949, chickpea production increased from 817 tons to well over 3,000 tons (Glegg, 1947; Rounce, 1949). To date, the crop has spread to many new areas of the mbuga soils where it is grown for cash and as a food crop. In the Mwanza cotton region, chickpea is grown in Kwimba and Geita districts, whereas in Shinyanga the crop is grown in Kahama, and Iramba districts (Fig. 1). A large proportion of the crop is bought by General Agricultural Products Export Corporation (GAPEX). Mwanza region produces 95 per cent of the national total (Billington, 1971).

The major pest problems of chickpea are chickpea blight caused by Ascochyte rabiae (Pass) which become prevalent if the rains exceed 6 inches (Glegg, 1947). The crop also suffers heavy losses to H. armigera which feeds on the leaves, flowers and pods. Spodoptera exigua is an occasional pest which feeds on leaves before pod formation (personal observation).

1.2.5 Tomatoes

Before the mid-1970's, tomato production was confined to backyard gardens and was of minor local importance. However, its

production, mostly as a cash crop, has been on the increase ever since 1978 especially in Mwanza region in the Kwimba, Geita, Ukerewe, Sengerema and Magu districts. Most of the crop is marketed in Mwanza and Shinyanga towns, and more recently to Bukoba between October and January, the low season in that area.

Tomatoes can be grown the year round but due to blight diseases especially during the heavy rains, many farmers prefer the dry season crop. Production figures has been difficult to obtain but the price of tomatoes at Mwanza food market range from 25 Tz sh per kg to well over 40 Tz sh. at low season (Personal observation and interview with tomato dealers at Mwanza market). At Mwanza market, tomatoes are in plentiful supply between June and September and scarce in March, April and May.

Other than blight, H. armigera can cause heavy losses to the fruits (Reed, 1965b).

1.3 Significance of H. armigera as a pest

1.3.1 Worldwide:

The genus Heliothis contains several well known and damaging pest species of agricultural crops, H. armigera being the most important in the Old World (Hardwick, 1965). The species is an important crop pest in the tropical areas of many developing countries where it has been recorded as damaging 60 cultivated plant species and at least 67 other plant species in 39 families across Africa, Asia and Australasia (Reed and Pawar, 1981).

In East and Central Africa, the species is a major pest of cotton in both peasant (Tunstall et al; 1959; Davies and Kasule, 1964; Reed, 1965a & b; Beeden, 1974; Rens, 1977), and large scheme agriculture (Balla, 1981 and Salama 1983). In India, Reed and Pawar (1981) estimated that the annual loss of the two major pulses, chickpea and pigeon pea caused by H. armigera could exceed USA \$300 million per year. In Southwest Asia including Turkey, Iran, Syria, Lebanon and Palestine the species causes heavy losses on cotton, tomato, tobacco, chickpea and maize (Hariri, 1981). H. armigera and H. punctigera (Wallengren) are serious pests of cash crops in Australia particularly cotton, oil seeds, horticultural crops and sorghum. H. armigera which replaced H. punctigera since 1970 (Wilson, 1974), was responsible for the abandonment of cotton cultivation on the Ord River Scheme in Australia and continues to be a threat on introduced replacement crops including sorghum.

The closely related species H. zea, the corn earworm, is a serious economic pest of maize and cotton in the USA, where H. virescens (F.), commonly known as the tobacco or tomato budworm is also a major cotton pest in the Americas.

In Tanzania, loss of cotton to the pest alone has been estimated to more than USA \$20 million annually (Reed and Pawar, 1981) which is a massive loss when related to the economy of the country.

H. armigera appears to become relatively more important as cropping is intensified and as inputs of fertilizer and water

increase. Thus, in the Sudan Gezira, the species became established as a major annual pest as opposed to an occasional and sporadic pest after the 1960's probably due to an intensification of land use with irrigation and with increased areas of groundnuts and wheat. Losses of cotton in the whole of the Gezira Scheme are severe in most seasons, while on sorghum grain in the same Scheme loss is estimated at 5 to 10 per cent (Balla, 1981). Similarly, in Northern Nigeria, H. armigera was a minor pest until the late 1960's when maize and tomatoes in irrigation schemes were introduced (Beeden, 1976). In Egypt, H. armigera became increasingly important as a pest of cotton from 1972 because of the construction of the Aswan Dam which enabled farmers to adopt a multiple cropping system thus resulting in the availability of the bollworm's host crops over a greater period than before the introduction of the irrigation scheme (Salama, 1983).

However, in some regions the species is of less economic importance, for example, in Uganda (Coaker, 1959) and in parts of South India (Reed and Pawar, 1981).

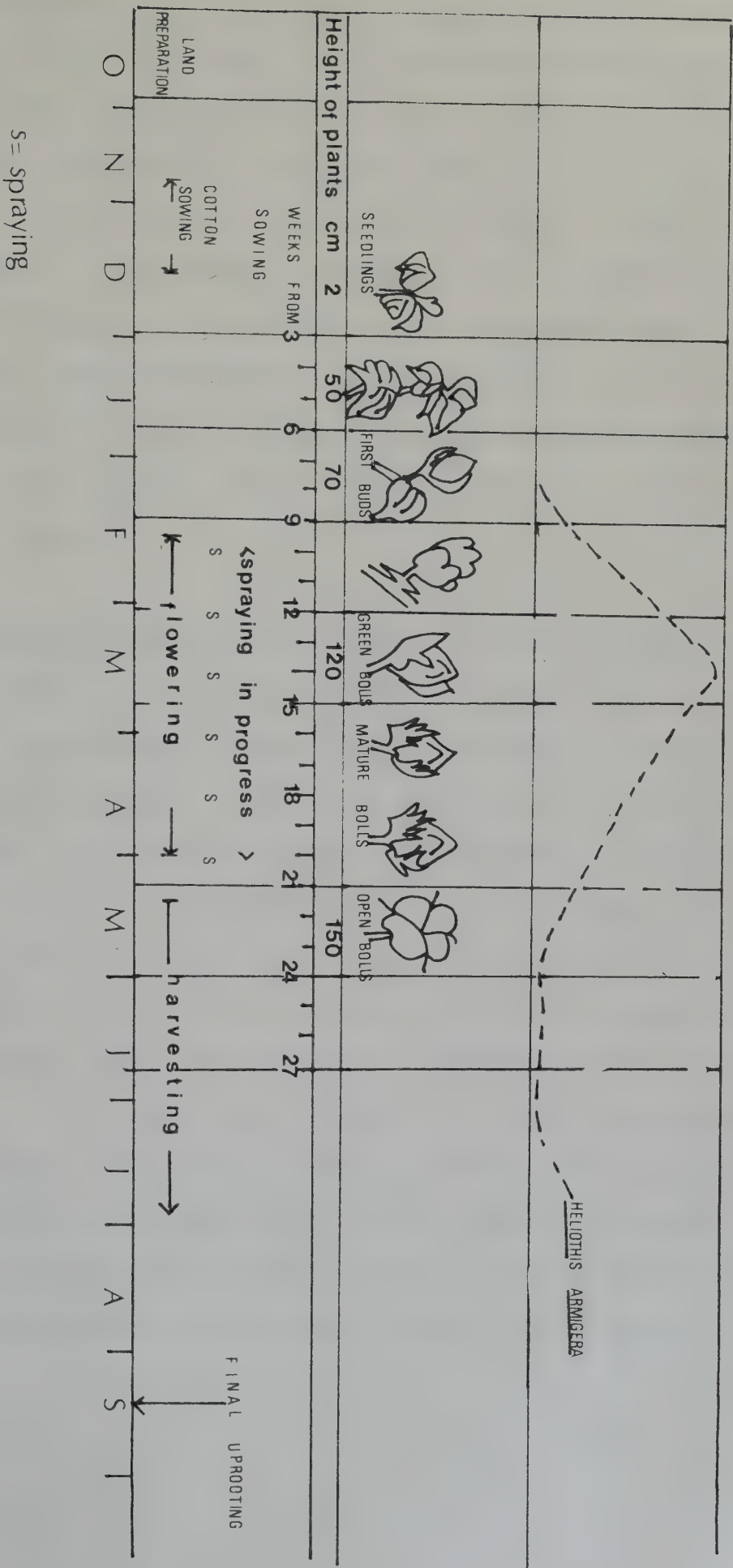
1.3.2 Western cotton growing area

In a preliminary survey of the WCGA by Pearson (Reed, 1970) H. armigera was identified as the most destructive pest of cotton and it was recommended that research efforts should be initially concentrated upon the pest. Following this recommendation, Reed started preliminary studies on the biology and ecology of the pest in 1962 at Ukiriguru, the cotton research centre.

In his studies, Reed found that more eggs were laid during the rainy period than in the dry season. The mean incubation period was 2.78 days and the larval period, from hatching to pupation, was 21.1 days. The pupation period was 16 to 18 days for males but shorter for females, depending on pupae weight. A diapause period of 30 to 171 days was also noted in the population between March and June, and this affected only about 4% of the population. The pest was important on cotton from February to April but also feeds on many other host plants. During the dry spell (August - October) the pest was in diapause and emerged at the beginning of the short rains in November - December when they feed and breed on Cleome, its wild alternative host. Between November and February, H. armigera fed on a variety of host plants including maize, sorghum and grain legumes. He observed that the recent increase in the severity of the pest on cotton in WCGA was a result of the replacement of sorghum by maize, since maize is not only an intermediate host but also a source of diapause pupae later in the season.

Following these observations, Reed (1965b) concluded that H. armigera in cotton could adequately and economically be controlled by DDT sprays. Thus, a fixed spray regime which has remained unchanged to date was recommended. A fixed spray regime was recommended mainly because for timely sown cotton in WCGA, peak flowering coincides with peak H. armigera infestation (Fig. 2) and spraying during this period would afford maximum protection to fruiting points and young cotton bolls. In addition, even for cotton sown outside the recommended sowing dates, the crop becomes attractive to ovipositing moths at

Fig 2
Timing and build up of H. armigera in relation to the growth stage of the cotton crop in WCGA Tanzania



flowering although it is not uncommon to have an infestation at the vegetative stage of the crop. And under the existing extension system, a fixed spray regime was easy and most ideal to the farmer. Thus, farmers were advised to apply six sprays at 2-week intervals beginning at first flower (10 weeks after sowing). This simple recommendation is not always justifiable since it ignores both temporal and spatial differences in pest infestation levels. In addition, the recommendation has faced practical problems including unacceptability by farmers, increased insecticide prices and adverse effects on H. armigera natural enemies that create conditions favouring resurgence.

Nyambo (1981) estimated that only about one-fifth of the cotton farmers in Tanzania spray their cotton fields, and that about half of those who spray apply an average of three sprays out of a total of six that are recommended. In addition, only half of the farmers who spray do so at the recommended dosage. Reduced number of sprays and low dosage rates are direct responses to the ever increasing cost of insecticides which is making cotton spraying less economic. For example, in the 1974-75 season, a farmer needed to produce only 100 kg seed cotton to pay for six sprays on a hectare. However, five years later, in 1980, this had increased to 150 kg, even using the same insecticide. Even with the recent government move to boost up cotton production in Tanzania through farmer's price as an incentive, the relative cost of cotton insecticides has continued to increase (Table 1), and therefore, economically, the farmer is not better off.

Table 1. Comparison of seed cotton prices and cost of insecticide (endosulfan 25% ULV) changes in Tanzania during 1980-81 to 1984-85 seasons

Year	Seed cotton price per kg		Insecticide* price per litre Tz.sh.	Cost of spraying 6 sprays per ha Tz.sh.	Cost of spraying	
	AR	BR			At fixed 1980-81 Price	kg/ha Adjusted per increased seed cotton price
80-81	3.70	1.70	26.00	390.00	100.00	100.00
81-82	4.70	2.50	28.25	423.75	114.50	90.00
82-83	6.00	3.20	32.90	493.50	133.40	82.25
83-84	8.40	4.20	36.25	543.75	146.90	64.47
84-85	13.00	7.40	71.90	1078.50	291.50	82.96

* All cotton inputs in Tanzania are bought through tenders

With a 176.5 per cent increase in the cost of spraying between 1980-81 and 1984-85 seasons, cotton spraying is likely to continue being unpopular especially among low income farmers who are the majority.

Increased reliance on insecticides especially broad spectrum insecticides now very popular in Tanzania, may increase the danger of reducing the activity of H. armigera natural enemies. Reed (1965b) observed a reduction of H. armigera larval parasitism at Ukiriguru from 27 per cent to 6.4 per cent within two seasons following increased use of insecticide at the research station.

Early sowing is strongly recommended to minimize loss by H. armigera on cotton, so in WCGA cotton should be sown between the end of November and the end of December and be ready for picking in May/June (Reed, 1965b). Thus, in a year when H. armigera population build up early, the early sown cotton may lose its bottom crop but will compensate later by producing a top crop during the main rains of April and May. The present cotton varieties grown in Tanzania are particularly suited to such compensatory growth provided soil moisture and nutrients are adequate. If on the other hand, the H. armigera population builds up later rather than earlier, the early sown cotton would have set its main crop and would therefore escape serious damage (Reed, 1965b). Unfortunately, cotton is often sown late in the season because the farmer gives early season priority to his food crops which also depend on the timing of the short rains.

H. armigera management in cotton in Tanzania has to date been centred on the cotton plant with little or no consideration of the different alternative host plants in the agro-ecosystem. Some of the cultivated food crops in this cotton area could play an important role in the bionomics of the pest. The majority of the food crops in the area including maize, sorghum, millet and grain legumes and tomatoes are alternative hosts of H. armigera. Reed (1965b) examined the role of maize in the build-up of the pest in cotton at Ukiriguru and concluded that early sown maize in WCGA should be banned to interrupt the build-up of the early generation of H. armigera on maize which later migrate on to cotton. However, with the present farming system in which food crops are given priority, the recommendation is impractical (Nyambo, 1981).

The recent government policy to establish 'Ujamaa' villages coupled with campaigns to increase crop production and the need for extra cash among the peasant farmers has led to a change in the farming system in WCGA. Maize production has become more popular in recent years and is gradually replacing sorghum and millet as the preferred food crop. The change to maize in WCGA is believed to have been accompanied by more frequent severe attacks of Heliothis on cotton (Reed, 1965b).

Short maturity compact headed sorghum varieties have replaced the traditional long maturity open head types. Compact headed varieties give protection to the bollworm from predators and parasites and therefore more larvae survive to the adult stage

(Doggett, 1964). This change in variety may have significantly affected the bionomics of H. armigera and the subsequent population which disperse onto cotton.

In the 1960's, tomatoes were of minor local importance (Reed, 1965b) but since 1978, commercial tomato production has been expanding notably in Mwanza region. Recent introduction of commercial tomato production under irrigation in Northern Nigeria coupled with large scale maize production resulted in the intensification of H. armigera as a pest of cotton (Beeden, 1976). Off-season production of chickpea, Cicer arietinum, on residual moisture on mbuga soils as a cash-food crop especially in Mwanza and Shinyanga cotton regions has been expanding since its introduction in 1932. Both these crops are good hosts for H. armigera and could act as a reservoir of the pest on cotton.

Since the introduction of Ujamaa villages ('villagilization' in 1967, cotton production acreage has increased both on individual holdings and on block and Ujamaa farms. Reed (1970) observed that the recent expansion and intensification of cotton growing was accompanied by increases in the loss of crop caused by insect pests.

The above changes in the farming system, crops and cropping sequence could have a significant impact on the status of H. armigera as a pest of cotton in WCGA. For example, according to Reed (1965a), August and September are dry months when H. armigera diapauses as pupae. However, the increased tomato and chickpea acreage during the

later part of the year which extends well into the dry season may have provided a bridge, thus enabling H. armigera activity to continue all the year round. Some of the crops could be potential sources of both pest and natural enemies, and could also be used to monitor the early season build up of the pest in order to effect better control on cotton. Crop-insect interactions occur at many different levels and in the case of H. armigera, are greatly complicated by the large host range and the fact that a large number of cultivated species are favoured hosts. The interactions resulting from this have been little studied in depth especially in the case of Western Tanzania where a considerable spread of sowing dates for different crops also add another factor in the complex. The interactions arising from this, especially between the main host crops and some of the weed host plants could be exploited to minimize crop loss by the pest.

The present study is an attempt to examine the bionomics of the pest in the small scale agro-ecosystems typical of WCGA, with emphasis on the development of improved integrated control strategies.

2 GENERAL CONDITIONS IN THE STUDY AREA

2.1 Climate

The climate has a well defined rainfall pattern which is weakly bimodal and a long dry season (Fig. 3). The figure shows the mean monthly total rainfall, recorded at Ukiriguru, from 1931 to 1985 and the mean monthly rainfall totals for the period 1980-85 when the study was done. During the study period, October and November had above average rainfall and this encouraged the planting of early maturing food crops which established well. However, December rainfall was below the long term average and this caused crop failures and delay in cotton sowing.

The mean temperature variations throughout the year, were low. The monthly mean maximum and minimum screen and insectary temperatures are shown in Fig. 4.

Ukiriguru is only 280 km south of the Equator and therefore variations in day length each year is less than one hour (Reed, 1970).

2.2 Location of the study area

Ukiriguru Research Institute is 1170m above sea level and is situated to the south-east of Lake Victoria, 4 km from Smith Sound. The location of Ukiriguru in relation to the cotton growing areas in WCGA is illustrated in Fig. 5 and the study area including the villages covered is shown in Fig. 6.

Fig 3 Ukiriguru mean monthly rainfall: Long term averages in comparison to the study period

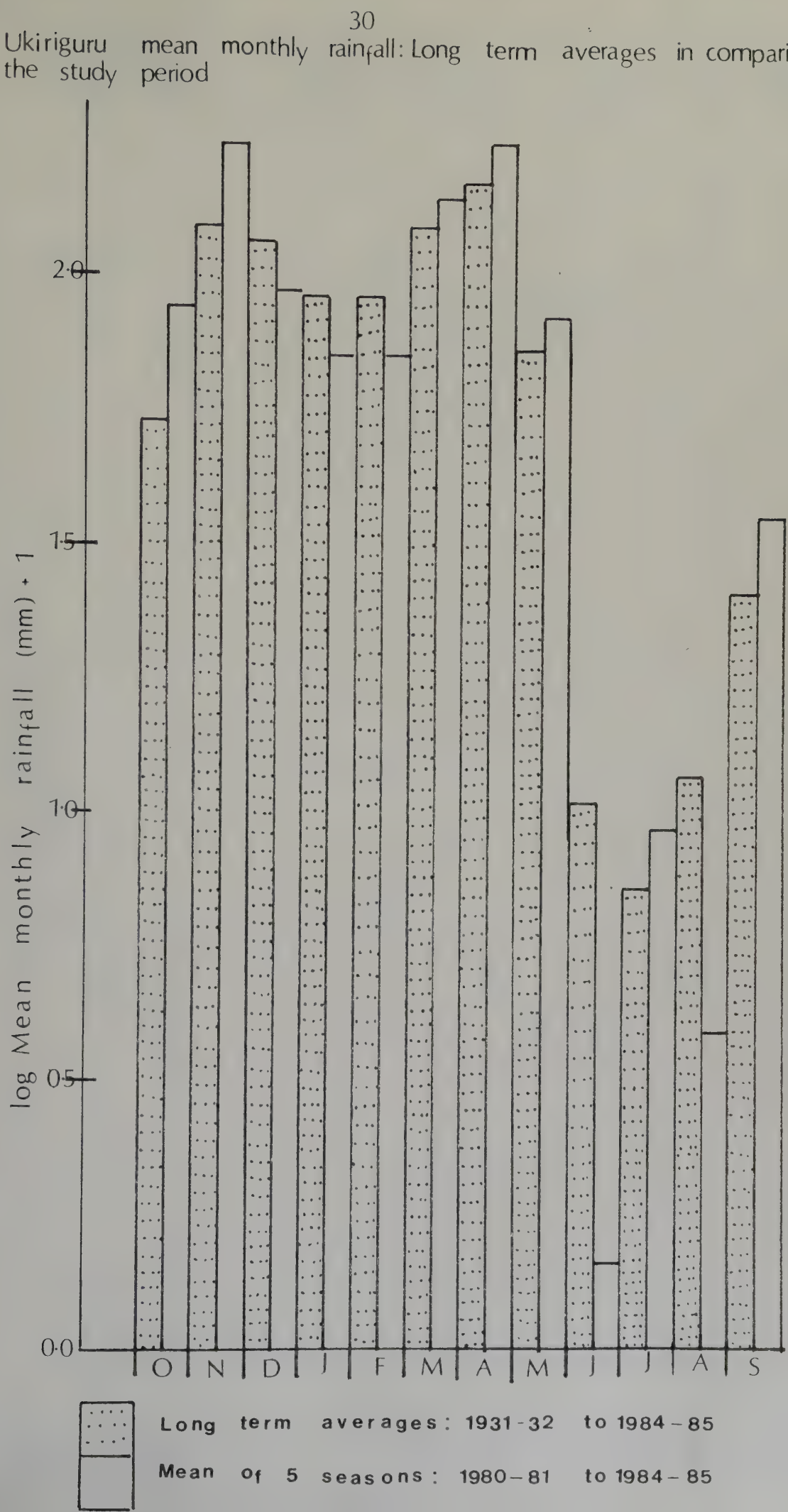
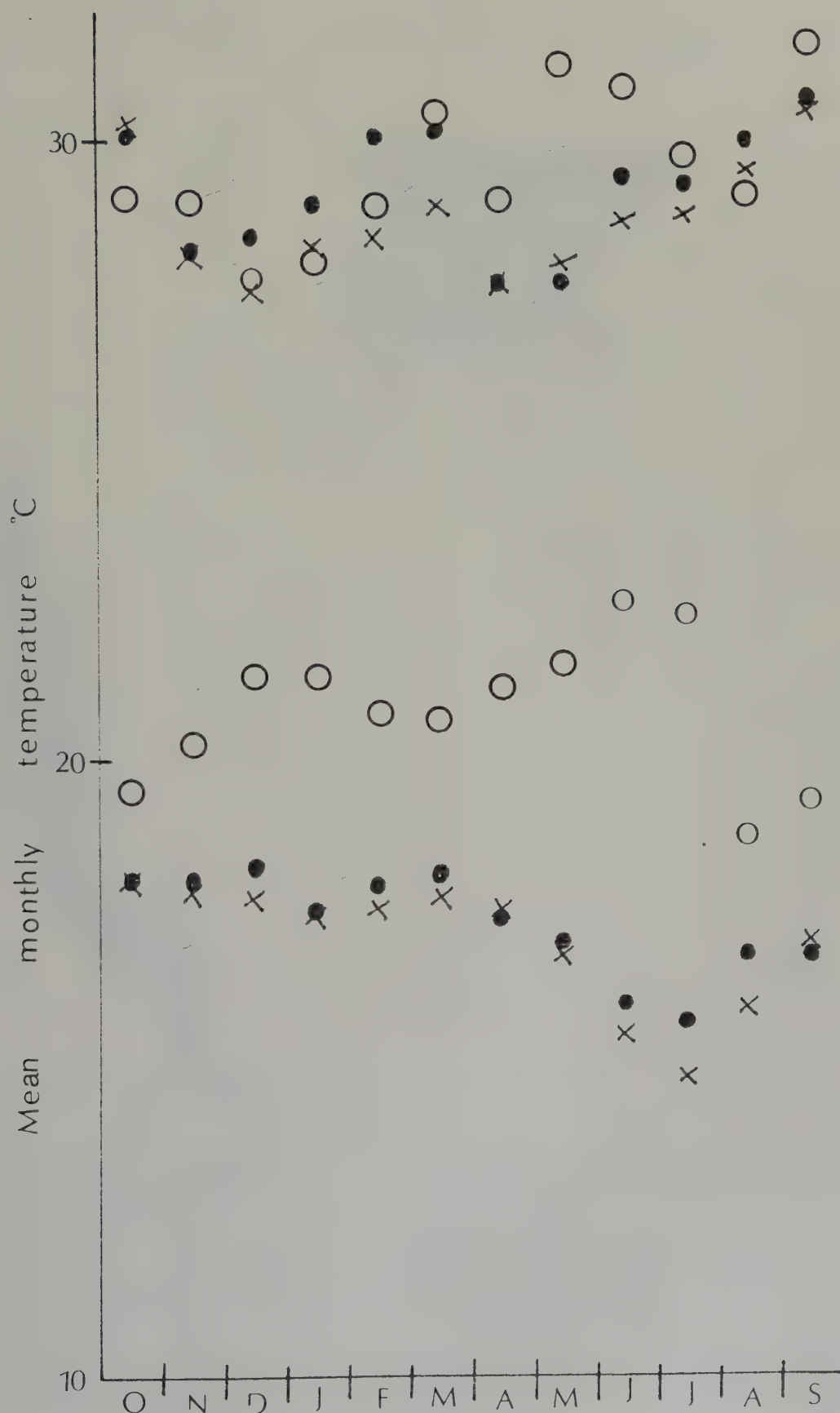


Fig 4

Ukiriguru mean monthly maximum / minimum screen temperatures °C ; Mean of 19 years in comparison to temperatures during the study period : Insectary temperatures also shown



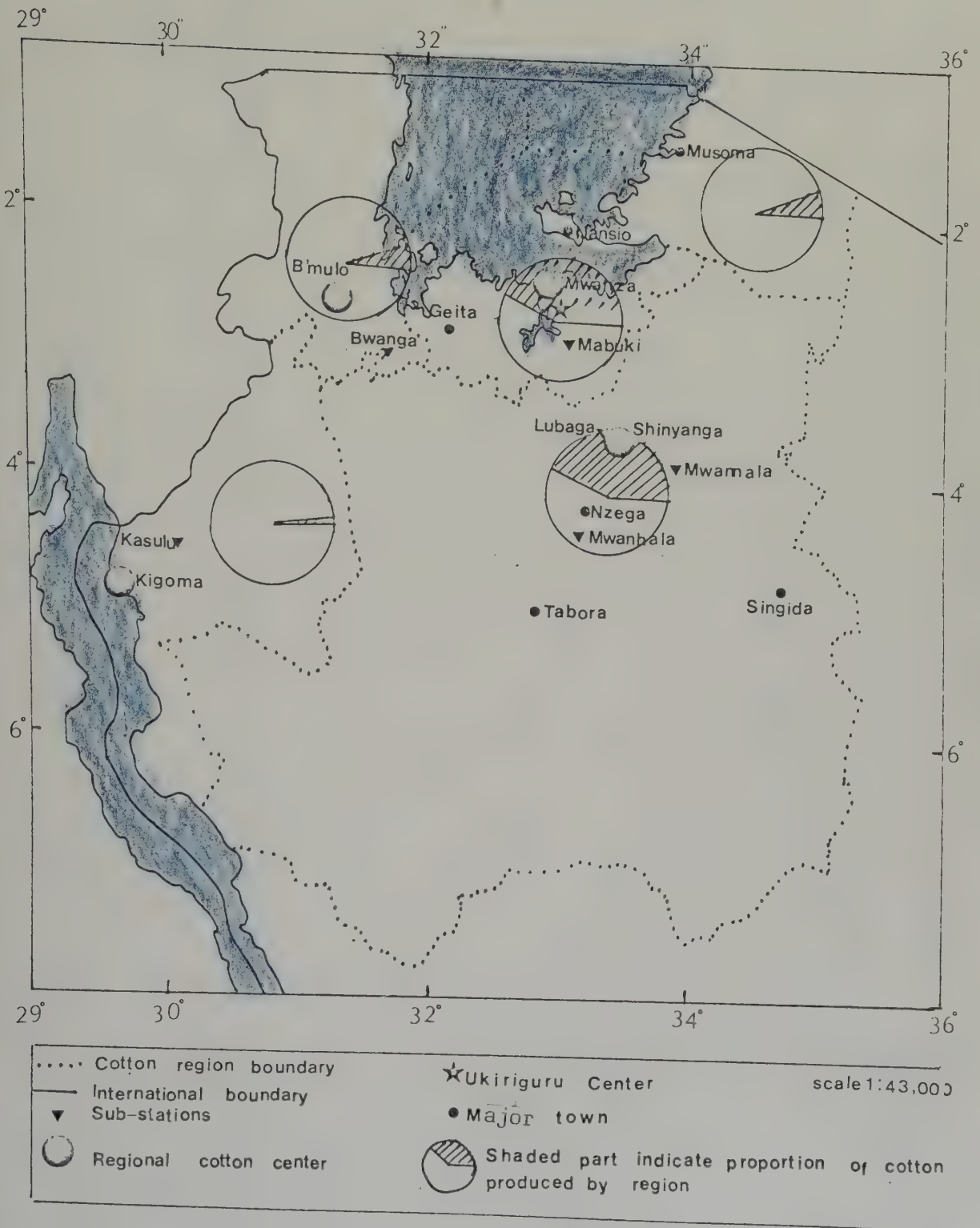
○ Insectary: 1983-84

× Long term mean 1962-63 to 1983-84

● Mean of 4 seasons 1980-81 to 1983-84

Fig5

Ukiriguru Research Center in relation to WCGA



The essential features of the soil catena (chain) in the study area include the hilltops, the footslope, the hardpan and the valley bottom. The hilltops are of large rocks of granite and some sandy loam soil in the crevices. The footslope, often referred to as the hillsands, forms the widest part of the catena and consist mainly of well drained sandy loam. The hillsands are the major cotton soils. Below the hillsand, at the margin of each valley is an impervious hardpan soil generally known as the 'itogoro'. At the valley bottom is a heavy, black, cracking clay locally known as the 'mbuga'. The mbuga soils are mainly for chickpea and sorghum production.

3 THE INCIDENCE OF H. ARMIGERA ON DIFFERENT HOSTS IN THE STUDY AREA

3.1 Larval populations

3.1.1 Surveying and collection of larvae

The study area, based at Ukiriguru Research Station, is in the Ukiriguru Ward which comprises the villages of Ngudama, Mwagala, Nyamikoma, Nyang'holongo, Busagara and Buganda (Fig. 6). The study covered the whole ward. Each village was visited twice a week and on each visit the scouts examined two crops or hosts on randomly chosen fields. Surveyed hosts were maize, sorghum, cotton, chickpea, tomatoes, and Cleome sp. (Capparidaceae). Cleome, locally known as 'mgagani' (Plate 1) is a wild alternative host plant of H. armigera found in most sites throughout almost all the year. The green leaves are used as spinach and also for medicinal purposes.

3.1.1.1 Sampling procedures. Sampling of H. armigera populations (eggs and larvae) began when plants reached stages attractive to ovipositing adult female moths, and continued until the crop had reached senescence (Attractive stages are discussed under 5.1.1).

In the first year, 1980-81 season, the sampling was done at 3-day intervals because being a particularly dry year few host plants survived the drought and grew vigorous enough to attract H. armigera. Therefore, there was a need to sample a very large number of plants to obtain sufficient information. Thus, twenty plants were chosen at random on each scouting day (Appendix 1). Any larvae and/or eggs found were counted and taken to the insectary for rearing to the



Plate 1a) Cleome sp. (Mgagani) at flowering in unweeded cotton field.



Plate 1b) Cleome sp. growing on the edge of a maize field: both host plants at flowering



Plate 1c) H. armigera larva feeding on Cleome flowers

adult stage and for observations on parasites and diseases. Additional larvae were also collected and taken to the insectary.

In the second, third, fourth and fifth seasons only 10 plants per host were sampled each time. Also, because the weather was more favourable than in the 1980-81 season, this led to growing of larger acreages of the crops in the study area and therefore more host plants were available. It was also decided to count and collect only larvae as the counting of eggs would in practice require a very experienced scout to do so accurately. Also, many of the eggs were damaged during collection. A set of random numbers were used to select the plants to be examined. During the study each set of host plants was examined once a week and on the same day in each village.

Surveying on maize began when the plants reached 50% tasselling and continued until the plants were at the dough stage. During the first season, the whole plant was searched for eggs and larvae but as knowledge of the distribution of eggs and larvae on the plant was gained, efforts were concentrated more on the tassels, silk and the cob for larvae and on the silk and leaves above cob area for eggs.

As with maize, surveying on sorghum began at 50% flowering and continued until the grains were past the dough stage.

Cotton was examined from the first square stage and continued until picking commenced. The whole plant was searched for eggs and larvae.

Chickpeas were examined from the seedling stage because these became attractive to H. armigera infestations before flowering. Scouting continued until the pods were dry.

The whole tomato plant was sampled with particular attention to the fruits and flowers where most larvae are found.

Sampling on Cleome began at the first true leaf stage and the whole plant was examined with special attention to the flowers.

The weekly field data for each host from the different villages were pooled to determine the mean level of infestation per plant for each host.

Thus,
$$\frac{\text{Total number of larvae recorded in a week}}{\text{Total number of plants examined in a week}} = \text{larvae per plant per week}$$

Thus, weekly levels of infestation on different host plants was established. The information obtained was used to determine the level and timing of infestation on different hosts, the relative attractiveness of the different hosts and the intercrop relationships.

3.1.1.2 Insect rearing and record keeping. In the insectary, the larvae were separated and reared individually in petri dishes to adult stage. The growth stage of the larvae, host plant, collection site and date were recorded. The larvae were observed daily for diseases and parasites until they either died or pupated. Records of

date of pupation, host plant, date of adult emergence, sex of adult and diseases and/or parasites were made.

If a larva or pupa was parasitized, this was noted and the individual was given an additional number. Records of the date of collection, nature of parasitism, host plant and stage (instar) at which the parasite emerged were kept. The parasitized larvae or pupae were left in the insectary until the adult parasite emerged in which case the date of emergence, order, genus and species of the parasite was recorded for each individual. Specimens were sent to the Commonwealth Institute of Entomology for identification where necessary. Dead diseased larvae specimens were sent to the Institute of Virology at Oxford for identification of the pathogen.

If a larva or pupa died of disease, this was sub-divided into either viral or bacterial, depending on symptoms just before or after death and as described by Whitlock (1973). All petri dishes containing such larvae were removed from the insectary daily before feeding the apparently healthy larvae as a further precaution against spreading disease. Larvae were always maintained in the insectary on the food plant on which they were originally collected. The food was collected daily from the field. This avoided the necessity to use artificial diet which was not easily available. Such a culturing method had the added advantage of identifying any diseases which may have been associated with the host material as it is possible that larvae feeding upon certain host plants can be more susceptible to pathogens than those feeding upon other hosts (Reed, 1965b; Callahan, 1962; Beeden, 1976; Vago and Cayrol, 1955).

To minimize disease spreading in the insectary, the glassware was heat sterilized once a week while the plastic equipment and working benches were regularly washed with a solution of 0.2% potassium hydroxide (Brown and Swaine, 1965). Furthermore, all glassware, petri dishes and brushes suspected of being contaminated with pathogens were immersed in 0.2% potassium hydroxide overnight after which they were washed and sun dried.

3.1.2 The level and timing of infestation on different hosts

The timing of H. armigera infestation is often closely related to the flowering pattern of its host and at Ukiriguru, the availability of suitable host plants overlap (Fig. 7) to give continuous generations throughout the year.

3.1.2.1 1981-82 season (Fig. 8).

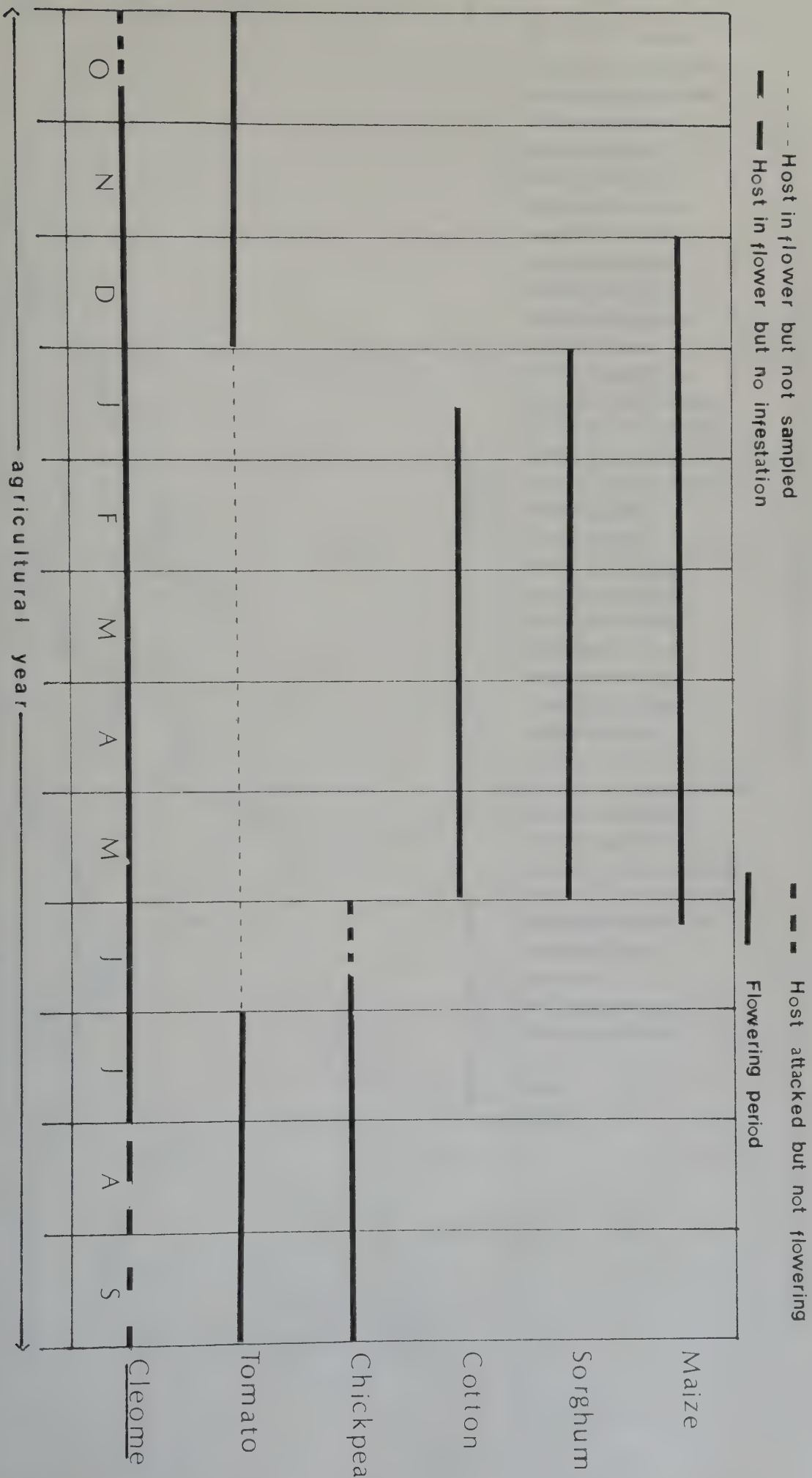
The rainfall distribution during the season was patchy over much of WCGA but Ukiriguru had adequate amounts for good crop establishment. The short rains in October - December were favourable for the early maize and sorghum crops.

On Cleome, about 7 larval peaks were observed between October and June, with the main peak in April, during the heavy rains. February and March was a period of low populations on Cleome possibly because of reduced rainfall amount. Between July and mid September no larvae were found on Cleome.

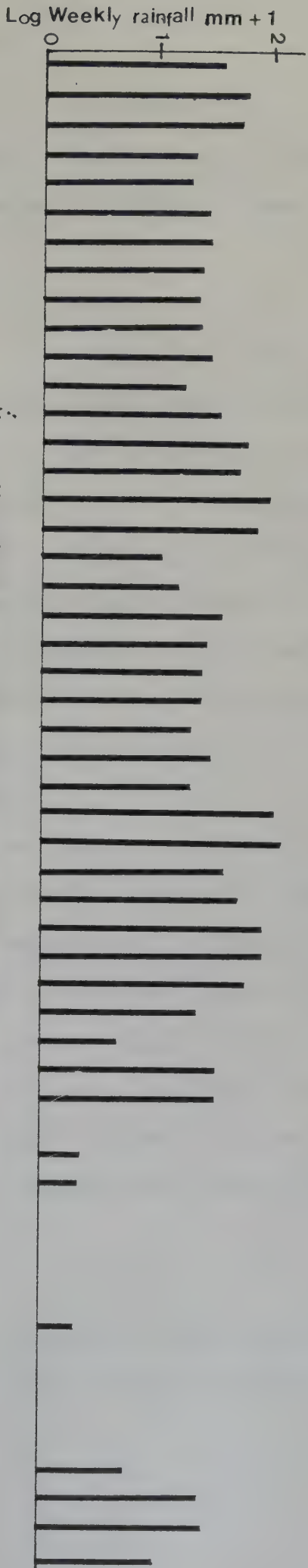
Populations on maize began to increase in early December and larvae were common up to mid May as a result of sequential sowing.

Fig 7

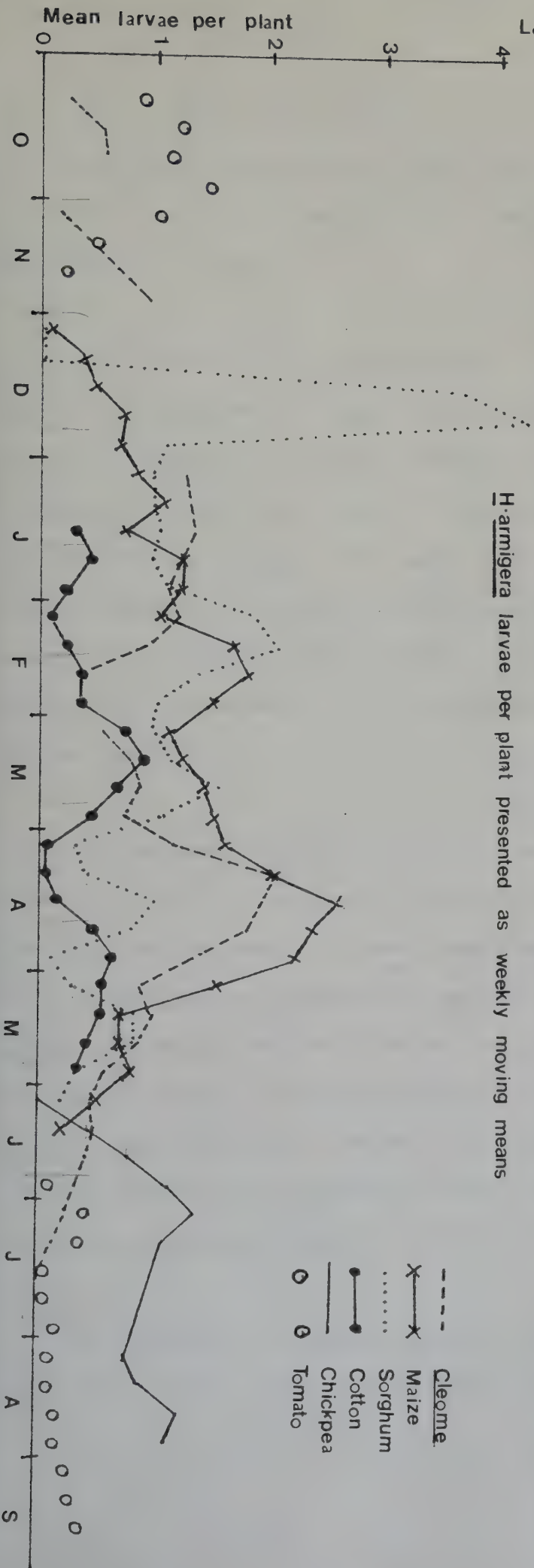
The main flowering periods of *H. armigera* host plants at Ukinguru: Summary of survey carried out from 1980-81 to 1984-85 seasons. Bold line indicate periods during which the host remain attractive to *H. armigera* in every seasons. The flowering periods in individual seasons may be shorter or longer.



Rainfall (mm) pattern presented as weekly moving totals



H. armigera larvae per plant presented as weekly moving means



Five larval peaks were recorded, with the main peak in April and overlapping the main peak on Cleome. The population peak in April was mostly on the long maturity maize which is usually in flower at this time of the year.

The infestation on sorghum began a week later than that on maize, and although the early peak was very high, the population declined rapidly by the end of December. Five larval peaks were recorded and this, as in maize, reflects the effects of sequential sowing and ratoon crops. A few farmers chop off the stalks after the first harvest in January to allow a ratoon crop to develop later during heavy rains in April and May. The harvest from the ratoon crop is relatively small but in a year when the first crop fails, it can be important.

Infestations on cotton began after mid January and damage was mostly confined to the leaves. Peak infestation occurred in March and this was followed by a small peak towards the end of May. The late season peak of infestation was not economically important as timely-sown cotton was ready for harvest, whereas for the late sown cotton, the rains in May were too low to enable bolls formed at this time to reach maturity. Overall, the level of infestation even at the time of the peak population in March remained notably lower than on maize, sorghum and Cleome.

The population on chickpea started in June and built up rapidly to a peak in early July, and thereafter remained at a high level to

the end of the season. Only two larval peaks developed.

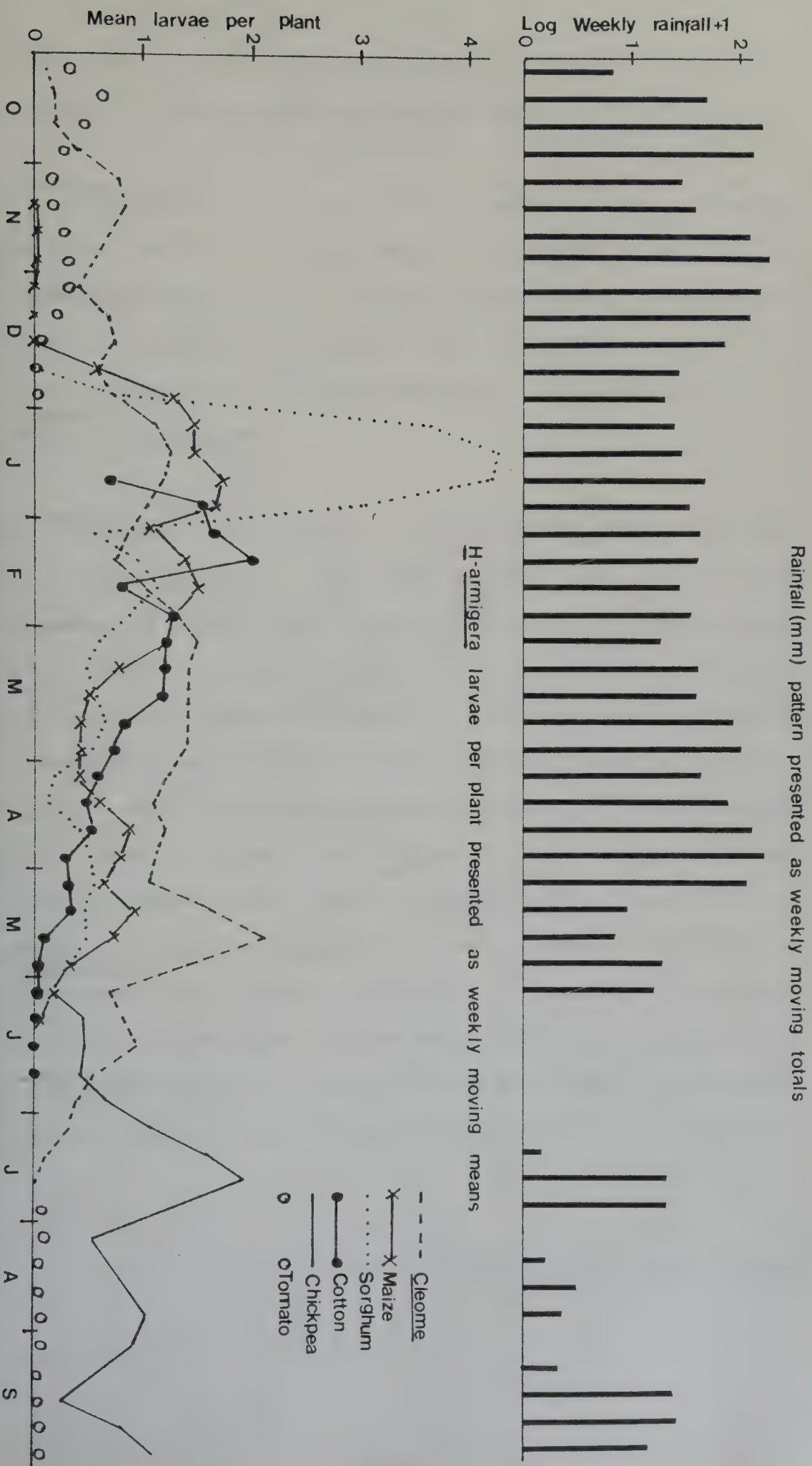
The infestation on tomatoes remained fairly low and, since it was not examined throughout the year, it is not possible to make valid comments on seasonal variability of the pest numbers.

3.1.2.2 1982-83 season (Fig. 9). The rainfall was heavier and more evenly distributed than in the previous season and the populations of H. armigera were higher in most areas of WCGA.

At Ukiriguru, Cleome again flowered throughout the year. The infestation began to increase rapidly from the beginning of October, reaching peak numbers in May. As in 1981-82 season, 7 larval peaks were recorded although the timing and level of the peaks were different. In the 1981-82 season, the population declined after January and remained low up to the end of March before reaching the main peak in April. During 1982-83 however, the population built up gradually between October and January, and continued to build up to an extended peak between February and April, with the highest peak being recorded in May, after the heavy rains. The period July to September was marked by complete absence of the pest on Cleome.

The infestation on maize started in mid-December reaching peak in January, and remained consistently high to the end of February. After February the level of infestation declined and remained continuously low up to mid April when a small peak occurred. By mid June the population on maize had disappeared. The last peak of

The seasonal abundance of H. armigera on its host plants at Ukiriguru 1982-83 season



infestation, as in the previous season, coincided with the main peak on Cleome but the population numbers were lower.

The population on sorghum started towards the end of December, two weeks than in the previous season. The population built up very rapidly to a sharp peak in January, also observed in 1981-82, and thereafter declined to a low level that persisted for the rest of the season. Four larval peaks were recorded, each successive one being smaller or less severe.

Similarly, the populations on cotton began a week late compared to the previous season, and built up to a sharp peak in early February, at a time when infestation on maize, sorghum and Cleome were declining. The first peak was short. However, although it declined by mid February, the level of infestation on cotton remained relatively higher than that on both maize and sorghum up to the end of March. Both maize and sorghum were adversely affected by the dry spell between February and March, but cotton being a more drought-tolerant crop, remained relatively more attractive to H. armigera. Similarly, Cleome did not seem to be as much affected as the cereal crops since it continued to support a substantial population of the pest. During April and May the infestation on cotton was lower than on maize, sorghum and Cleome, an observation also made last season. By mid June, no larvae were recorded on cotton.

The timing of the infestation on chickpea was similar to last

season. The populations began to build up on the crop in early June, reaching peak in July. The population continued up to the end of September when harvesting ended. At the end of this season, it was becoming clear that the infestation on chickpea began as that on maize was declining and that the first generation on chickpea coincided with the last larval generation on Cleome.

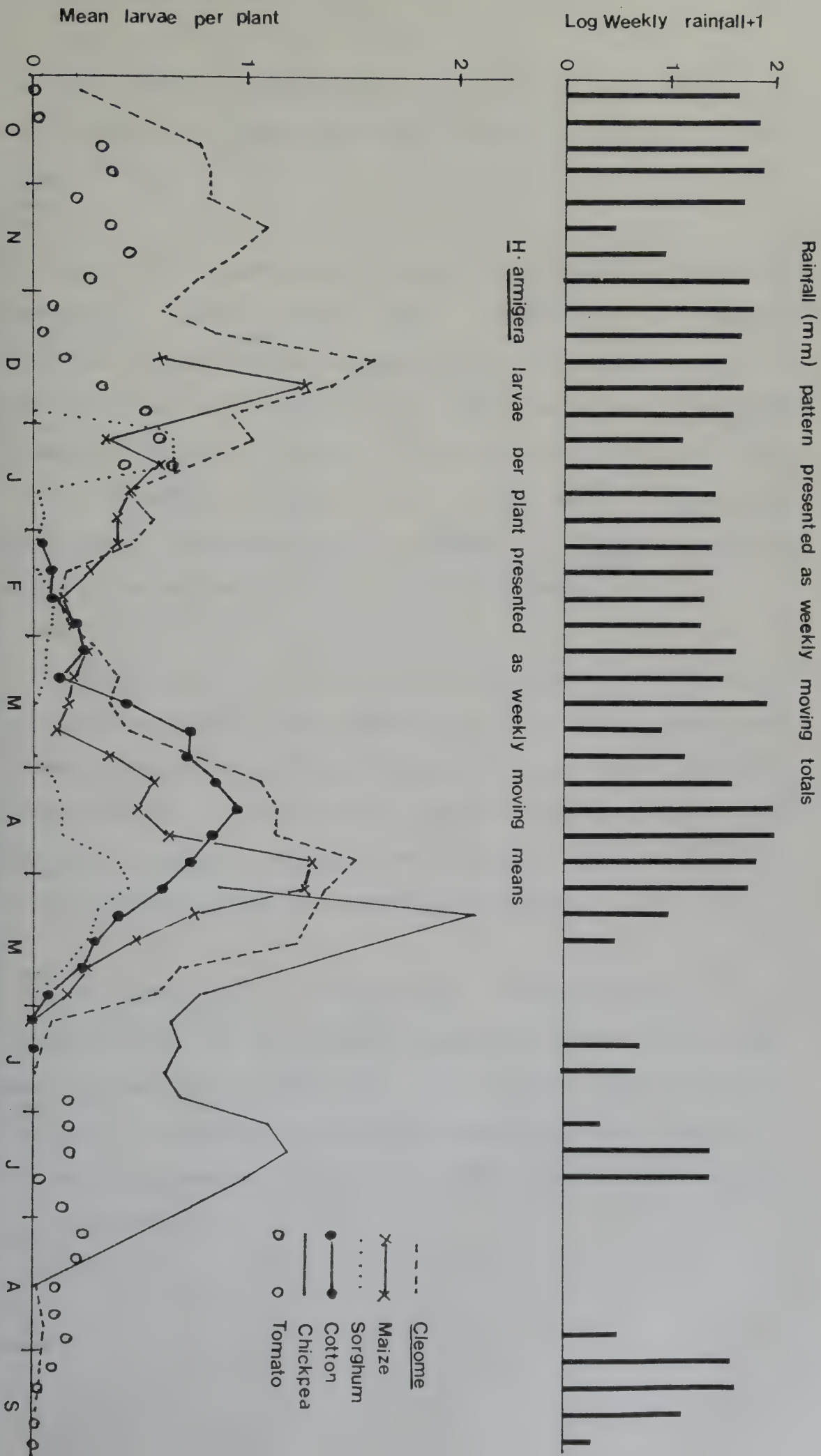
The H. armigera population on tomato remained relatively low compared with the other hosts although the crop was not monitored throughout the year..

3.1.2.3 1983-84 season (Fig. 10). The rainfall distribution was very erratic over much of WCGA and although the short rains were adequate for sowing the early season food crops, a dry spell between January and March caused widespread crop failures. The expected heavy rains came in April but these were also short lived. As a result, land preparation for the chickpea crop was difficult and the area under the crop was particularly low.

Cleome was available throughout the year and H. armigera larvae were found on the weed throughout the year except for a period between mid June to mid August. A few H. armigera larvae were also present after mid August which did not occur in the previous season. Two main population peaks were recorded. The first main peak extended between October and January and the second one occurred between end of March and May. By mid June no larvae were found on Cleome. In contrast to the past two seasons, January-March was a

Fig 10

The seasonal abundance of H. armigera on its host plants at Ukiriguru 1983-84 season



period of very low infestations. The severe mid season drought may have rendered the Cleome plants less attractive to ovipositing adult moths.

Early season maize began flowering in mid December and although H. armigera numbers remained high until the end of December, subsequent maize crops were adversely affected by the drought and were therefore not suitable hosts. After March, the H. armigera population began to build up on the long maturity maize, which started flowering in April. This second peak of infestation coincided with the main peak of infestation on Cleome and sorghum. By the end of May no larvae could be found on maize.

Sorghum was similarly affected by the drought. The first sown crop started flowering after December and the H. armigera population level was moderate compared with the two previous seasons. The first larval generation occurred in early January and was very short lived. Although larvae were present on sorghum from January to May, the level of infestation was low throughout the season.

The infestation on cotton began in February and built up gradually to a long and extended peak between March and May, thus causing heavy damage to the crop. At the time of peak infestation, the level of infestation on maize and sorghum was low. However, as the level of infestation on maize and sorghum began to increase, that on cotton declined.

Chickpeas were sown rather early mostly as a compensatory food crop after the drought (Section 1.3.4). The H. armigera infestation began to build up on the crop immediately at the beginning of May. Two identifiable peaks were recorded between mid May and July. After mid August no larvae were found on chickpea. It is interesting that the first peak of infestation overlapped the late season generations which occurred on maize, sorghum, cotton and Cleome. Valentine (1955) working at Ilonga (Eastern Cotton Growing Area - ECGA) observed that while the numbers of larvae were decreasing in cotton during July, large populations were recorded on chickpea. Such a situation is likely to occur for early sown chickpea (Section 1.3.4). This would be the situation in the Manawa Ginnery cotton zone where early chickpea sowing is a common practice.

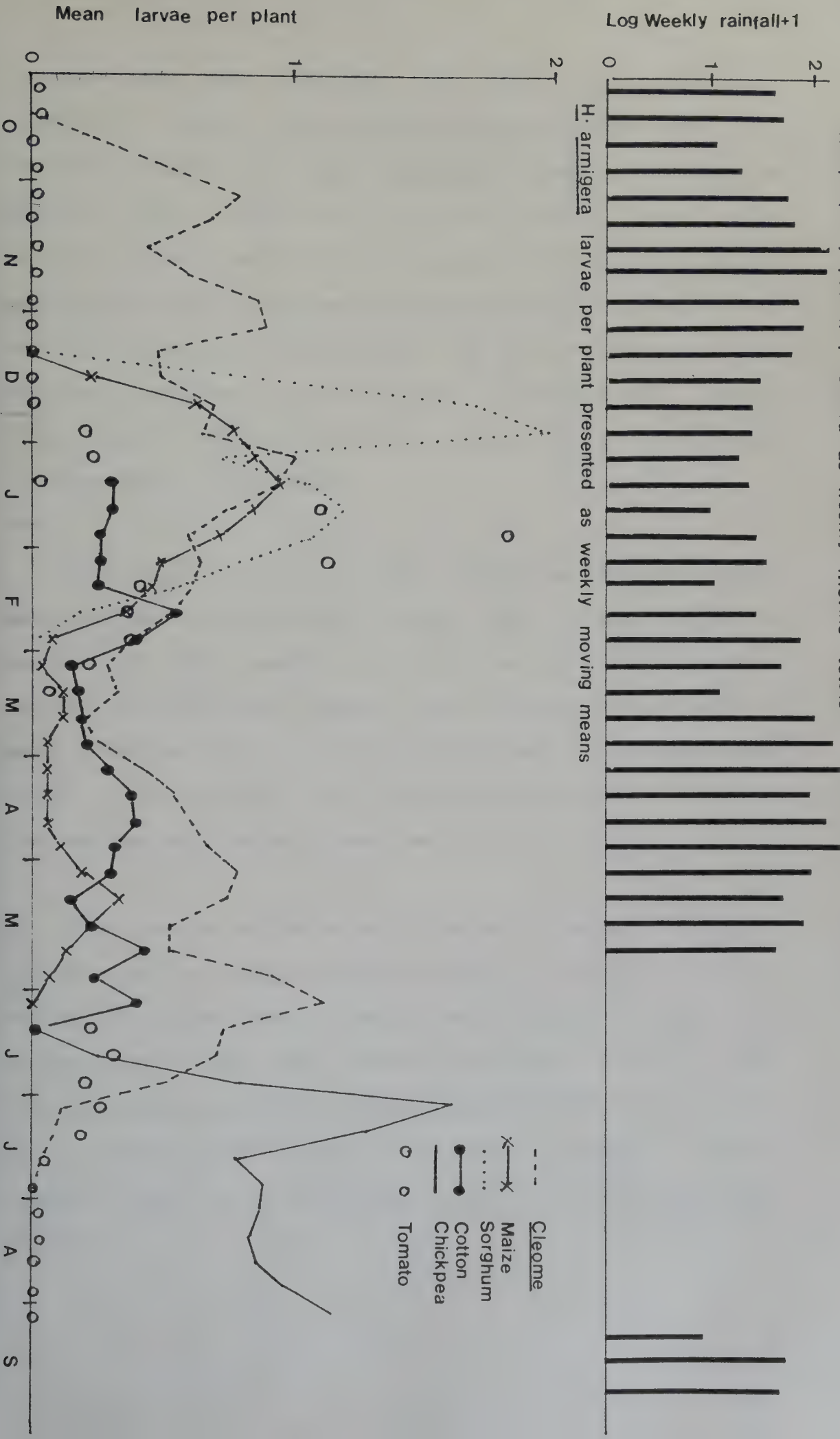
The level of infestation on tomatoes was generally higher than in the past two seasons, possibly because a high proportion of the crop is normally watered, whereas the other crops are rainfed. Since most of the alternative hosts failed to grow vigorous and lushy, tomatoes were the best choice for the pest during the 1983-84 season.

3.1.2.4 1984-85 season (Fig. 11). The rainfall distribution over much of WCGA was heavier and less erratic than 1983-84 season, and almost identical to 1982-83; and although there was a mid season drought, it was a successful agricultural year.

Infestations on Cleome started in early October but the population did not begin to increase until mid October when it went

Fig 11

The seasonal abundance of H. armigera on its host plants at Ukiriguru 1984-85 season



up rapidly to a peak in November. Two peaks were recorded between November and December just before infestations on maize began. The third peak coincided with the first peak of infestation on maize and sorghum, a similar observation also made in 1982-83 season. After mid June, no larvae could be found on Cleome. The population decline on Cleome between mid January and March was possibly a result of the severe dry spell during that time of the year, an observation also made during the same time of the season in 1983-84 season. The mid season drought in 1982-83 was less severe and its effect on general plant growth was less pronounced.

Maize started flowering in early December and the first larval generation occurred in January. However, with the onset of the dry spell between mid January and March, the level of infestation declined and by the end of February, very few larvae were recorded on maize. March and April was also a period of very low infestations on maize. A late season peak built up on the late sown maize in May but this was also very low and disappeared by the end of May.

Infestation on sorghum began at the end of December. The first generation was very high, similar to 1981-82 and 1982-83 seasons, and persisted throughout January. The subsequent level of infestation as on maize and Cleome, was affected by the dry spell, for the infestation began to decline rapidly from the middle of January, and by the end of March no larvae were found on sorghum. In most seasons, several larval generations occur on sorghum between April and May.

Five larval peaks were recorded on cotton. The first peak was moderately high and occurred in mid January, with a small peak in February. The highest and most damaging population occurred between March and April at a time when Cleome was the only attractive host for the pest. Consequently, although the level of infestation was lower on cotton relative to Cleome per plant host, it was almost twice as much that on maize.

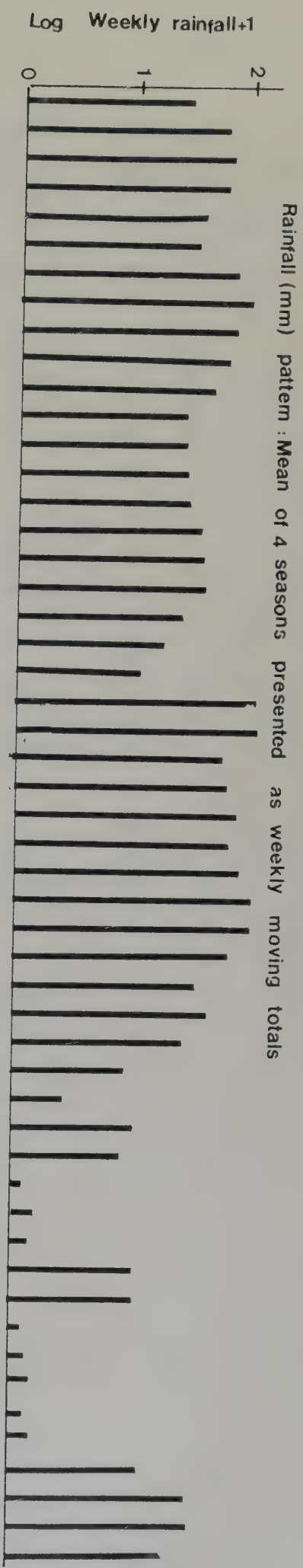
The heavy rains extended well into May and this caused delays in chickpea sowing. Excessive soil moisture at sowing causes the seeds to rot. Sowing began towards the end of May and extended to June. H. armigera infestations began in the middle of June on the earliest sown crop, and the first peak was recorded in July. As in previous seasons, the first generation on chickpea overlapped the last generation on Cleome, thus forming a bridge between the rainy and dry season crops.

Between June and July tomatoes were more heavily infested than in most seasons. However, the level of infestation was still lower than on other hosts.

3.1.2.5 Summary of four seasons work. Considerable variations occurred between the amount and distribution of rainfall in the different seasons, so it is difficult to formulate an 'average' year. However, the overall average pattern of H. armigera population changes at Ukiriguru during the study period, is summarized in Fig. 12. Generally, the level and timing of infestation within and

Fig12

Summary of the seasonal activity of H. armigera on its host plants at Ukiriguru 1981-82 to 1984-85 seasons in relation to rainfall



H. armigera seasonal activity: Mean of 4 seasons. Larvae per plant presented as weekly moving means

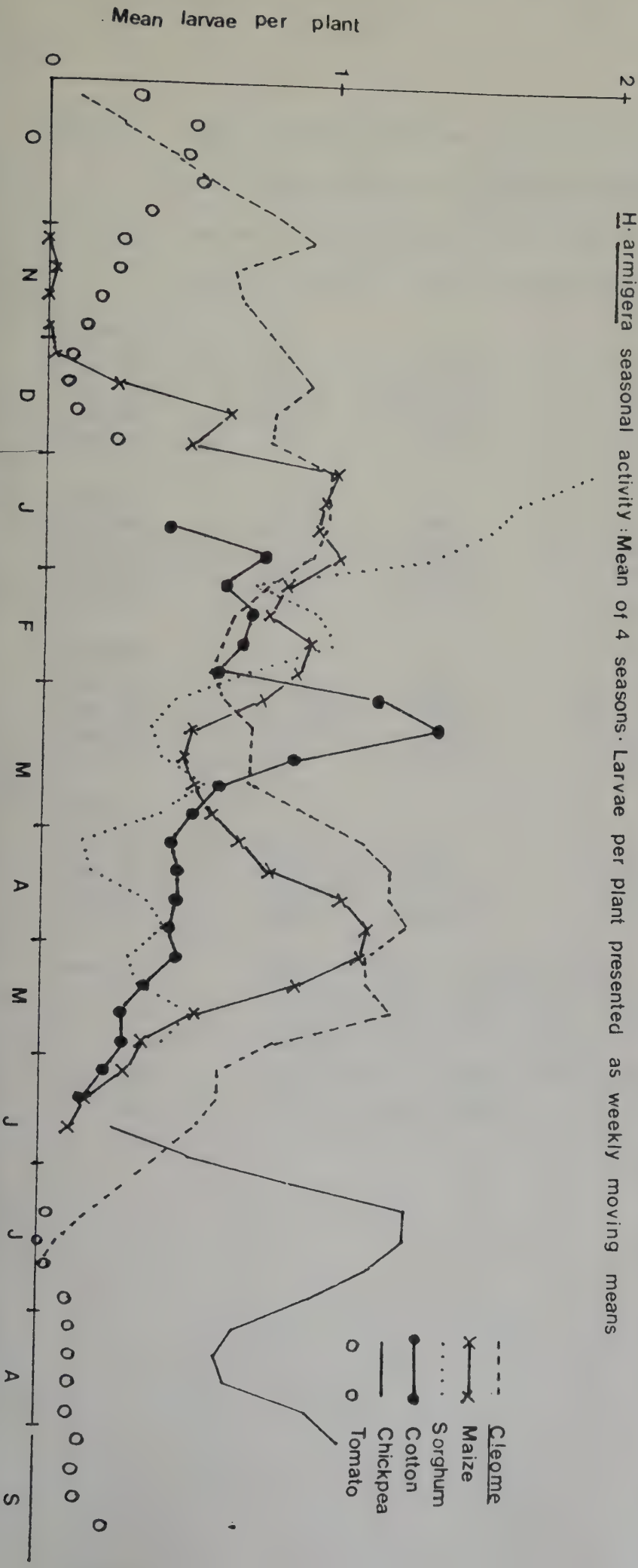


Table 2. The relationship between weekly moving rainfall total (mm) and the larval population on Cleome, cotton, maize, and sorghum for the period 1981-82 to 1984-85 seasons: The regression equations where \bar{x} = rainfall and y = larval populations were as follows

Cleome sp

1981-82 :	$y = -1.4571 + 0.0983x;$	$r = +0.747****df = 44$
1982-83 :	$y = 0.060 + 0.0457x;$	$r = +0.3720***df = 50$
1983-84 :	$y = 0.0157 + 0.0659x;$	$r = +0.5197****df = 50$
1984-85 :	$y = 0.106 - 1.167x;$	$r = -0.1197 \text{ n.s.} df = 40$

Maize

1981-82 :	$y = 0.0551 + 0.079x;$	$r = +0.2541 \text{ n.s.} df = 27$
1982-83 :	$y = 0.0567 + 0.061x;$	$r = +0.3838* df = 24$
1983-84 :	$y = 0.0205 + 0.053x;$	$r = +0.4088* df = 23$
1984-85 :	$y = 0.094 - 5.256x;$	$r = -0.5357** df = 24$

Sorghum

1981-82 :	$y = 0.2969 - 0.088x;$	$r = -0.2131 \text{ n.s.} df = 26$
1982-83 :	$y = 0.2192 - 0.037x;$	$r = -0.082 \text{ n.s.} df = 20$
1982-84 :	$y = 0.0238 + 0.030x;$	$r = +0.2206 \text{ n.s.} df = 19$
1984-85 :	$y = 0.193 - 2.325x;$	$r = -0.3573 \text{ n.s.} df = 10$

Cotton

1981-82 :	$y = 0.064 + 0.007x;$	$r = +0.0506 \text{ n.s.} df = 18$
1982-83 :	$y = 0.014 + 0.075x;$	$r = +0.5073** df = 22$
1983-84 :	$y = 0.009 + 0.056x;$	$r = +0.5908*** df = 20$
1984-85 :	$y = 0.084 - 0.0002x;$	$r = -0.2379 \text{ n.s.} df = 18$

Where n.s. - statistically not significant

* - statistically significant at $P = 0.05$

** - statistically significant at $P = 0.01$

*** - statistically significant at $P = 0.005$

**** - statistically significant at $P < 0.001$

between seasons appears to be influenced by the amount and distribution of rainfall. The timing of the rains determines the sowing dates whereas the amount and distribution of the rain determines plant establishment and growth and flowering and consequently the timing of the first infestations. However, dry weather conditions tended to cause drastic population decline in most seasons. Thus, the seasonal data on the level of infestation on different hosts and the amount of rainfall from 1981-82 to 1984-85 seasons was analysed by regression method to establish the relationship between the pest population levels and the amount of rainfall. Overall, there was a significant positive correlation between the amount of rainfall and the build up of the pest population on Cleome, maize and cotton (Table 2). Thus, rainfall is one of the important factors which favours the build up of the pest population on its different alternative hosts.

Overall, the generations from the different alternative hosts overlap to give a continuity of larval populations throughout the year (Fig. 12). Assuming each peak represents a generation (with a 5-weeks generation interval), six larval generations develop on Cleome between October and mid-July, four on maize, five on sorghum and cotton and two on chickpea. On tomatoes the number of generations was not determined because the host was not monitored throughout the season.

At the beginning of the short rains (October - December) the pest population builds up on Cleome and tomatoes, with Cleome as the

main host between October and early December. Two larval generations occur on Cleome between October and mid-December before the early sown maize becomes attractive for oviposition. Some maize may become attractive to ovipositing H. armigera moths in November but the main infestation does not occur until the end of December when early sown sorghum also begins flowering. Thus, in early January, the third generation on Cleome would coincide with the second generation on maize and the first generation on sorghum (Fig. 12).

The population of the first generation on sorghum which occurs in January is very large but short duration, whereas subsequent larval generations are progressively smaller and less severe and by the end of May no larvae are found on the crop. The first crop is sown timely and therefore gets adequate amounts of rainfall for good establishment and growth and this may contribute to the higher level of infestation compared to later crops which often grow less vigorous and thus less attractive for oviposition.

The short rain period is followed by a relatively dry period in February which has both direct and indirect effect on the survival of H. armigera. In years of severe drought during February as recorded in the 1983-84 and 1984-85 seasons, host plants wilted and died prematurely, whereas cotton plants shed leaves and aborted their flowers and small bolls. This resulted in reduced pest population levels because the plants become less attractive for oviposition, and nutritionally less suitable for any developing larvae. As a result, many larvae are likely to die of starvation and/or have reduced

growth. The fecundity of the adults is also likely to be reduced due to lack of flowering plants to provide nectar which is necessary for egg maturation.

After the mid season dry spell, the pest populations on Cleome and maize build up rapidly during the heavy rains and reach a peak between March and May. The population on cotton begins to build up in mid January at a time when the infestation on other alternative hosts is declining, reaching peak numbers in March. The peak population in March is the most damaging on cotton as the crop is at peak flowering. After March the infestation on cotton declines and remains relatively low compared to pest populations on Cleome and maize, and is probably less important in terms of damage to the crop.

Towards the end of the main rains the pest population disperses onto chickpea in mid June. The first generation on chickpea overlaps the last larval generations on maize and Cleome, thus forming a bridge between the rainy and dry season crops. Chickpea remains attractive to H. armigera between mid June to early September, and thereafter tomatoes continue as a major cultivated host.

4 HELIOTHIS ARMIGERA LARVAL MORTALITY FACTORS

Sampling, rearing and data collection have been discussed in Section 3.1.1.1 and 3.1.1.2.

In order to assess the possible role of mortality factors for H. armigera management, the larval instars at which death occurred were recorded. Field collected larvae may remain in the insectary for a period varying from a few hours to several days before a parasite emerges or a disease symptom become evident. Therefore, each field collected larva was classified as small (1st and 2nd instar), medium (3rd and 4th instar) or large (5th and older) on the day it was brought into the insectary. Records on the approximate instar of the larvae when the parasite larvae or pupae emerged or became visible and/or diseases symptoms appeared were also made.

This data is summarized in Fig. 13-32 and Tables 3-13 and Appendix 4 & 5 which gives weekly information on the level of parasitism, diseases (virus and bacteria) and also other unidentified mortality factors for larvae from each host. The percentage mortality due to diseases or parasitism was calculated on a weekly basis. The information thus obtained was used to analyse the overall seasonal relationship between pest population numbers in the field and mortality factors on the different hosts.

The overall weekly data on deaths due to different mortality factors and the total numbers of larvae observed were combined to

Table 3. Total numbers of larvae of H. armigera which were collected from the field and reared in the insectary from 1981-82 to 1984-85

1. Cleome sp.

Calendar Week	Seasons				Calendar Week	Seasons			
	1981-82	1982-83	1983-84	1984-85		1981-82	1982-83	1983-84	1984-85
40	9	10	17	0	25	25	44	0	35
41	16	2	81	1	26	11	50	0	35
42	16	24	113	81	27	2	12	0	9
43	-	57	37	141	28	8	2	0	3
44	-	176	143	38	29	3	0	0	4
45	7	130	214	51	30	0	0	0	0
46	9	117	120	41	31	0	4	0	0
47	17	65	77	124	32	0	0	0	0
48	44	88	100	360	33	0	3	0	1
49	25	72	167	145	34	0	0	6	0
50	48	57	298	23	35	0	0	3	0
51	-	72	84	136	36	0	0	0	
52	-	110	218	108	37	0	0	1	
1	27	142	135	43	38	0	0	0	
2	26	88	94	65	39	0	0	0	
3	-	89	17	164					
4	15	42	53	64					
5	43	42	37	57					
6	11	82	14	31					
7	14	58	5	67					
8	8	91	32	141					
9	1	49	39	125					
10	-	45	21	13					
11	41	50	20	86					
12	39	64	32	11					
13	21	36	128	15					
14	3	43	100	19					
15	8	101	99	72					
16	40	75	99	95					
17	90	19	131	43					
18	50	56	110	67					
19	77	61	87	48					
20	105	69	66	75					
21	155	128	41	79					
22	68	95	5	75					
23	45	99	1	151					
24	22	59	0	98					

Table 3. (Continued)

2. Maize

Calendar Week	Seasons			
	1981-82	1982-83	1983-84	1984-85
48	0	0		
49	11	0		
50	38	0	162	2
51	9	43	108	155
52	20	106	164	91
1	4	209	73	123
2	46	194	36	136
3	54	98	44	260
4	46	118	57	59
5	62	136	54	41
6	22	68	16	6
7	71	100	3	27
8	59	52	29	4
9	63	21	20	3
10	17	14	3	0
11	13	17	6	1
12	32	24	2	0
13	101	44	20	4
14	131	11	17	0
15	135	52	22	3
16	150	47	45	0
17	179	8	54	16
18	114	50	103	41
19	80	68	16	27
20	23	46	5	7
21	104	20	8	2
22	11	4	0	2
23	21	0	0	0
24	2	0	0	0
25	0	0	0	0

3. Sorghum

Calendar Week	Seasons			
	1981-82	1982-83	1983-84	1984-85
50	17			
51	65			
52	99	104		29
1	168	426	12	93
2	108	128	0	259
3	87	192	4	212
4	80	36	2	53
5	25	49	0	31
6	117	56	2	10
7	88	70	1	18
8	115	38	0	12
9	35	17	7	0
10	115	19	8	0
11	87	46	1	0
12	40	20	0	1
13	18	14	0	1
14	14	9	10	0
15	4	31	0	0
16	0	93	82	1
17	16	57	109	0
18	15	77	39	0
19	9	22	4	0
20	25	53	17	0
21	54	0	0	0
22	32	0	0	0

Table 3. (Continued)

4. Cotton

Calendar Week	Seasons			
	1981-82	1982-83	1983-84	1984-85
3	20	101		23
4	10	115		0
5	17	125	1	25
6	11	105	4	0
7	4	102	4	7
8	12	117	28	28
9	6	204	4	0
10	15	105	1	1
11	31	65	129	4
12	19	56	203	39
13	23	28	215	49
14	1	13	79	7
15	0	58	43	2
16	7	37	132	11
17	7	5	44	17
18	75	24	31	10
19	61	18	18	5
20	54	2	37	3
21	50	1	14	35
22	30	14		13
23	4	3		9
24	3	1		

5. Chickpea

Calendar Week	Seasons			
	1981-82	1982-83	1983-84	1984-85
18			151	
19			175	
20			258	
21			115	
22		33	66	
23	00	65	33	
24	81	84	113	00
25	178	143	90	86
26	238	186	73	193
27	212	240	73	368
28	374	717	133	88
29	183	810	136	92
30	303	128	140	204
31	322	83	55	111
32	226	171	34	160
33	315	358	0	108
34	203	255	0	110
35	62	178	0	269
36	00	119		
37	0	78		
38	0	217		
39	0	34		

Table 3. (Continued)

6. Tomato

Calendar Week	Season			
	1981-82	1982-83	1983-84	1984-85
40	42	10	2	3
41	85	34	13	5
42	99	18	48	0
43	0	11	13	0
44	0	4	20	1
45	31	6	58	0
46	12	19	43	0
47	2	20	11	0
48	0	0	2	0
49	0	4	2	0
50		0	23	0
51		0	27	0
52		0	82	10
1		12	45	5
2		17	18	0
3				104
4				104
5				36
6				12
7				27
8				6
9				7
24				22
25				4
26			5	7
27	1		6	7
28	4		0	2
29	2		0	4
30	0	3	1	1
31	3	3	0	1
32	5	0	5	0
33	0	7	14	1
34	18	10	6	0
35	5	3	5	0
36	11	6	10	
37	30	7	6	
38	16	2	3	
39	0	1	0	

give monthly totals which were used to calculate the proportion of the different mortality factors on a monthly basis for all the host combined (Appendix 2).

4.1 Seasonal distribution and abundance of diseases and parasites of *H. armigera* larvae on different hosts in the study area

The total field collected larvae observed in the insectary from each host are shown in Table 3 for the four seasons during which the study was done. Weekly numbers observed were a direct reflection of the field population densities (Appendix 3 and Table 3).

4.1.1 1981-82 season-general trends

Larval mortalities on the different hosts are summarized in Fig. 13. Three peaks of mortality occurred. A small peak occurred in October - November which was mostly due to diseased larvae from tomatoes and Cleome. The second peak extended between December and February with parasitism as the major mortality factor (Fig. 13). This was particularly evident on sorghum (Fig. 14c). After February, parasitism declined and remained persistently low throughout the season. The disease level continued to increase and reached a peak between March and June, causing over 20% larval mortality on maize and Cleome (Fig. 14a & b). The late season mortality peak after June (Fig. 13) was recorded on larvae collected from chickpea which did not show any specific disease or parasitism symptoms. The majority of the affected larvae died at the prepupal stage. Before death the larva shrunk and died of dessication. Immediately after death the cuticle remained tough and eventually hardened into a blackish mummy.

Fig 13

Mortality of H. armigera larvae in the Ukiriguru vicinity 1981-82 season presented as total monthly percentages

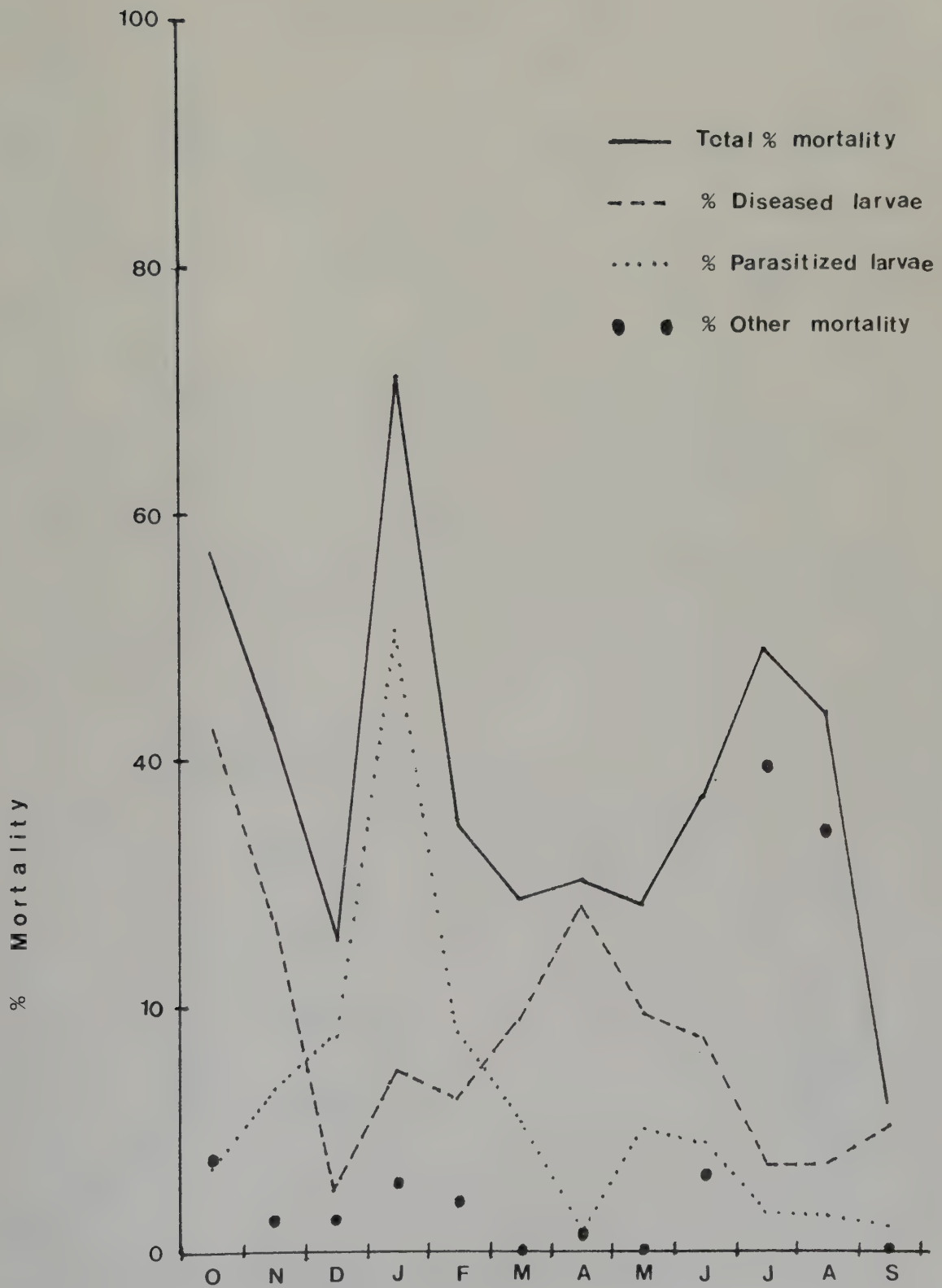


Fig14. The relationship between the level of infestation and mortality factors (diseases & parasitism) on field collected *H. armigera* larvae in 1981-82 season presented as weekly means

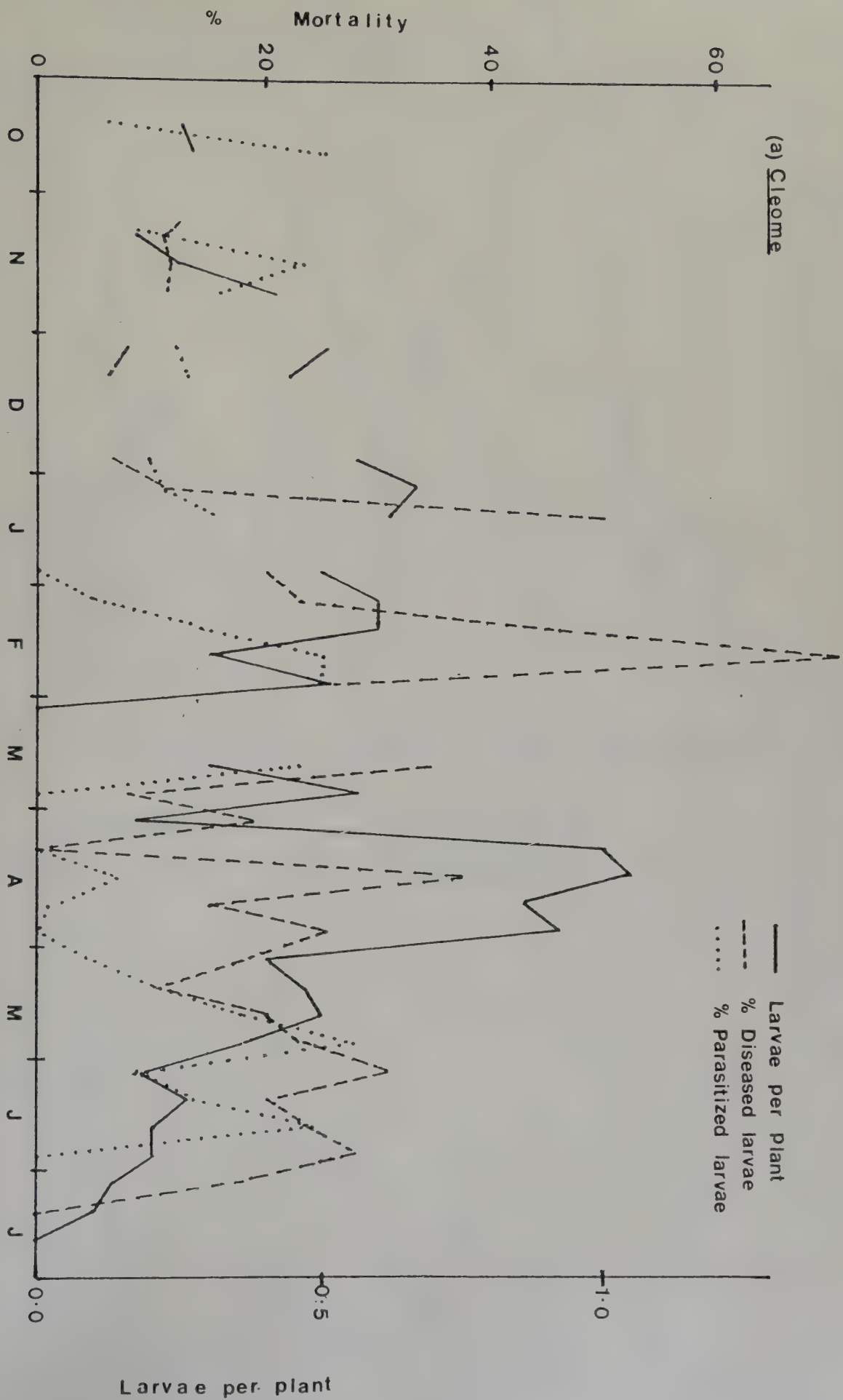


Figure 14 continued

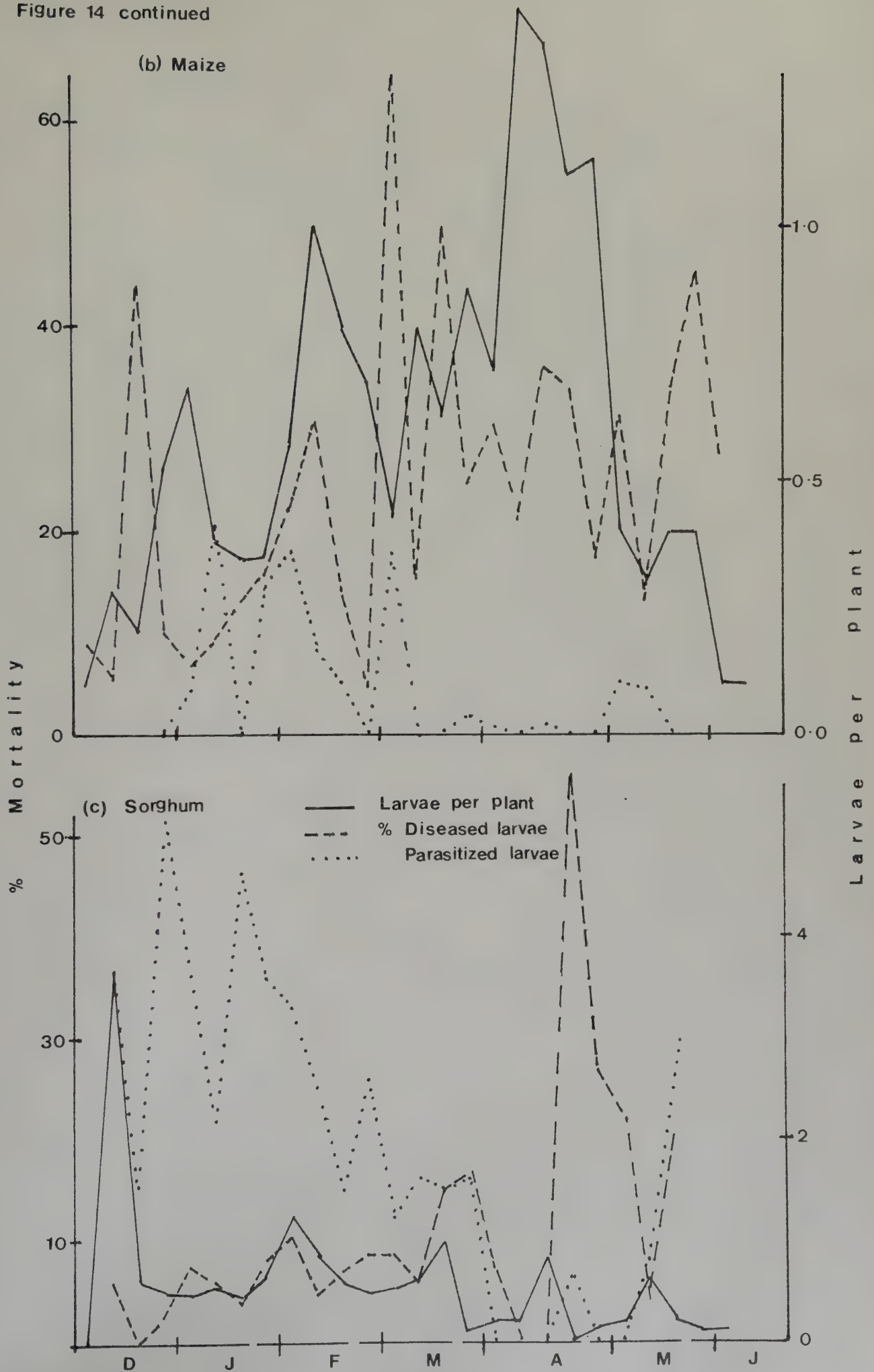


Figure 14 continued

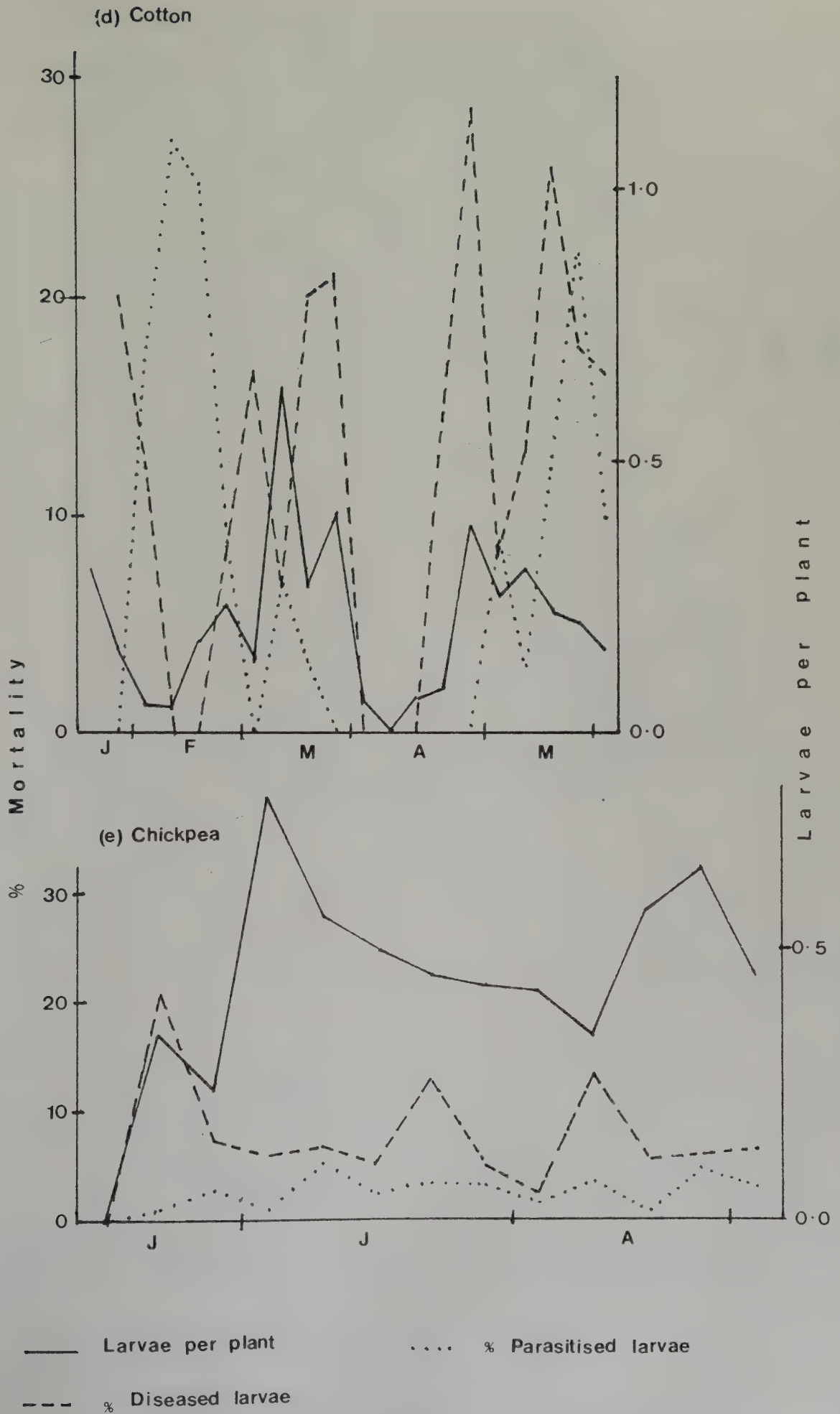


Figure 14 continued

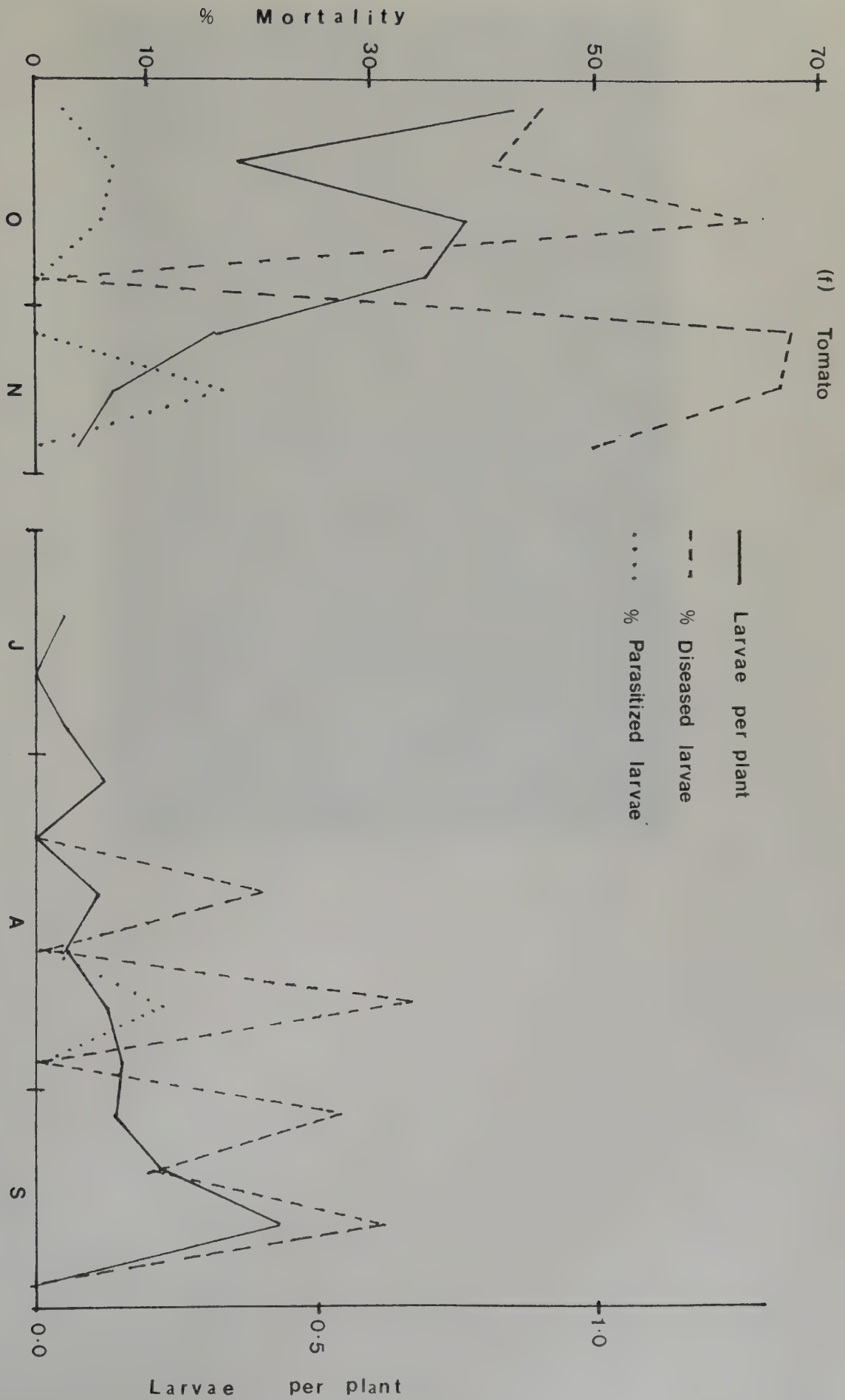




Plate 2. H. armigera larvae feeding on a sorghum head

A few specimens were also recorded from tomatoes and Cleome. Specimens were sent to the Oxford Institute of Virology but no disease organism was detected.

The relative level of H. armigera field population in relation to mortality factors (diseases and parasitism) on the different hosts is summarized in Figure 14. Overall, larval diseases were more common on Cleome, maize, cotton and chickpea whereas parasitism was highest on sorghum and lowest on chickpea and maize.

On cotton and maize, the level of larval disease tended to be density related since percent mortality increased as the level of infestation increased (Fig. 14b and d). The level of larval parasitism on sorghum was very high especially between December and early March (Fig. 14c) compared to maize and cotton. The differences in the level of parasitism between maize and sorghum could be because on maize the larvae feed within the silks and cobs where parasites are likely to be less effective than on sorghum where the larvae are exposed (Plate 2).

Parasitism on chickpea was persistently low and did not show any identifiable peaks (Fig. 14e). On cotton, parasitism occurred in two peaks, one in mid February just before routine spraying was in full operation and again towards the end of May, after the end of routine spraying on most fields (Fig. 14d). Both peaks were recorded before and after the peak of H. armigera population in March.

4.1.1.1 Diseases - Larval diseases (virus and bacteria) were important mortality factors on all the different hosts but the intensity and distribution of the different pathogens varied.

The daily records of visual symptoms of larval diseases are summarized in Tables 4, 7, 9 and 11 and in Figures 15, 19, 23 and 27. For each host, the percent of disease due to virus was calculated as follows:

$$\% \text{ Mortality} = \frac{\text{Total number of larvae with virus symptoms}}{\text{Total number of larvae with disease symptoms}} \times 100$$

To confirm the identity of the presence of virus and bacteria in the population, dead diseased larvae specimens were sent to Dr. T.W. Tinsley of the Institute of Virology at Oxford, U.K. for identification. Several of the specimens were identified as having Baculoviruses (Nuclear Polyhedrosis Virus - NPV) whereas the majority were affected by bacteria, with a few having fungal organisms. Both NPV and bacteria diseases were recorded on larvae collected on almost all the different hosts but the level varied (Fig. 15).

The two pathogens tended to be mutually exclusive especially on Cleome, maize and cotton (Fig. 15). However, larvae infected by NPV were recorded more on Cleome and maize than the other alternative hosts. Moreover, larvae bred and reared on cotton flowers in the laboratory succumbed readily to NPV when these were fed food

Table 4 Mean monthly summary of the proportion of larvae of H. armigera with viral and/or bacterial infections during 1981-82 season.

Cleome sp

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Oct	0.0	100.0	1
Nov	20.0	80.0	5
Dec	50.0	50.0	6
Jan	21.0	78.9	19
Feb	70.4	29.6	27
Mar	25.0	75.0	16
Apr	38.8	61.1	36
May	9.4	90.5	74
June	13.9	86.0	43
July	50.0	50.0	2
Aug	0.0	0.0	0
Sept	0.0	0.0	0

Maize

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Dec	0.0	100.0	9
Jan	50.0	50.0	14
Feb	19.5	80.4	46
Mar	21.2	78.8	33
Apr	38.8	61.2	196
May	23.0	77.0	100
June	33.3	66.6	3

Sorghum

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Dec	0.0	100.0	1
Jan	0.0	100.0	18
Feb	0.0	100.0	27
Mar	16.6	83.3	24
Apr	15.4	84.6	13
May	5.5	94.4	18

Table 4 (Continued)

Cotton

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Jan	0.0	100.0	2
Feb	33.3	66.6	3
Mar	16.6	83.3	12
Apr	33.3	66.6	3
May	2.8	97.2	36
June	0.0	100.0	5

Chickpea

Month	% Virus	% Bacteria	Total Number of Diseased larvae
June	36.6	63.3	30
July	42.2	57.7	71
Aug	7.3	92.6	68
Sept	0.0	100.0	6

Tomato

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Oct	0.0	100.0	117
Nov	0.0	100.0	27
Dec	0.0	0.0	0
July	0.0	0.0	0
Aug	0.0	100.0	8
Sept	0.0	100.0	14

Fig 15

Mean monthly % mortality due to virus and bacteria on H. armigera fed collected larvae and observed in the insectary during 1981-82 season

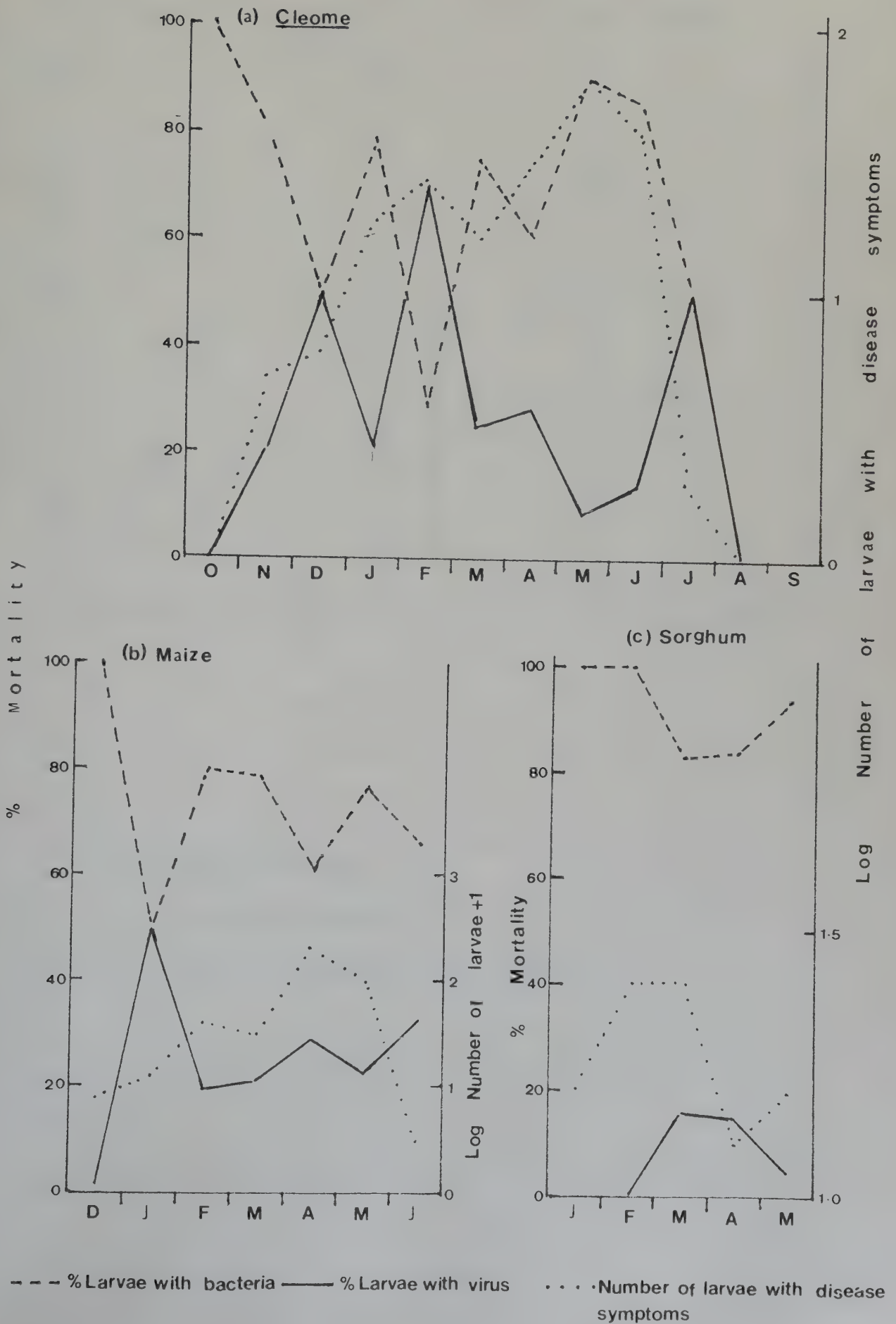
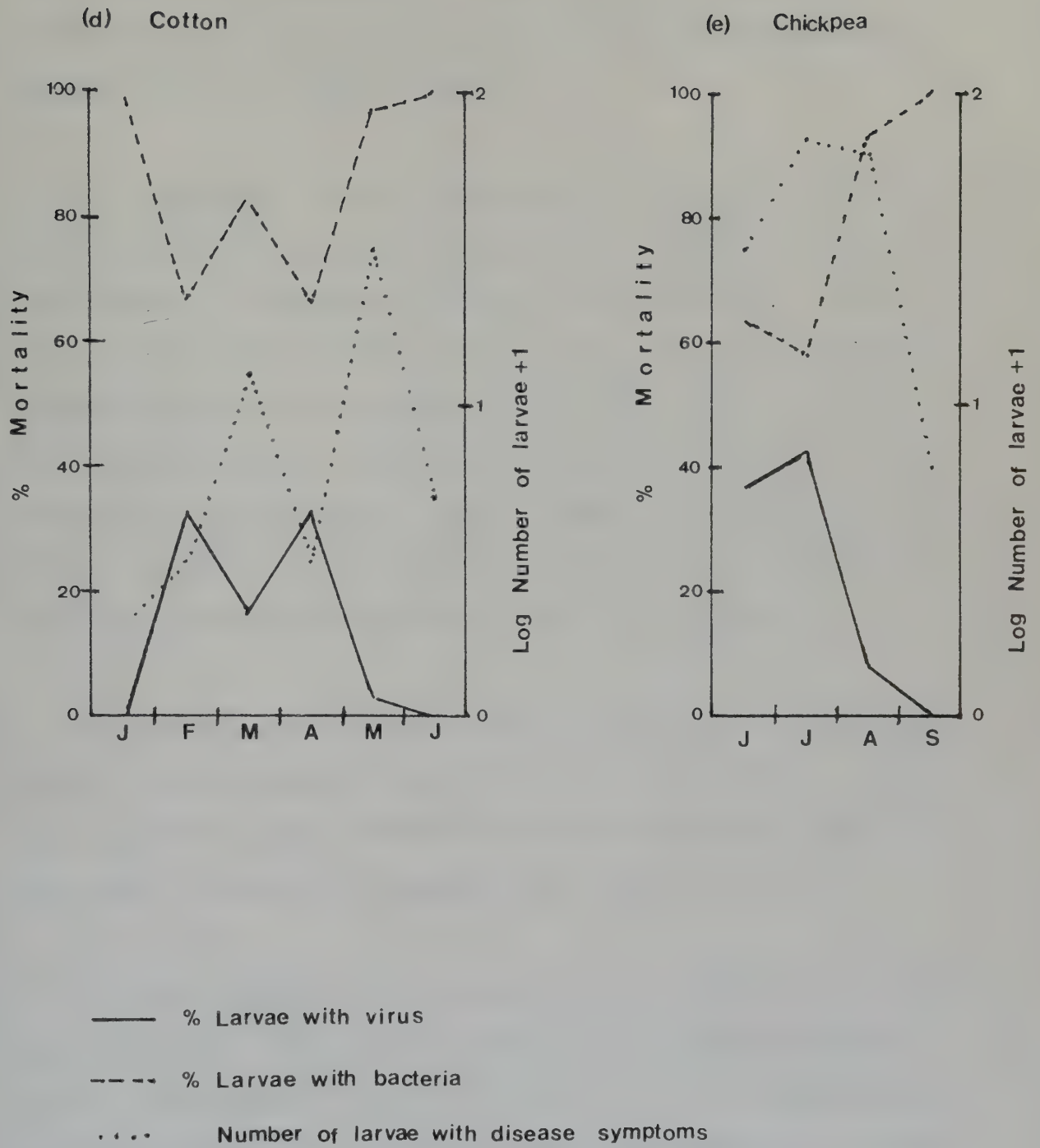


Figure 15 continued



contaminated with the disease. Larvae with bacteria were more common and occurred at a higher level on all the different alternative H. armigera host plants than NPV (Fig. 15).

4.1.1.2 Parasites - Larval parasitism was recorded on all the alternative hosts of the pest but the number of species involved and the intensity of parasitism differed in time and space. Overall, eight species were recorded and six of them were identified by the Commonwealth Institute of Entomology (Table 5). Date of collection, host plant and stage (instar) of development of the larvae were recorded for each parasitized larvae. These data indicated the time of the year when a certain parasitic species was active under field conditions, the host plant and the larval stage attacked.

The daily records for each host were summarized into monthly totals for each individual parasite genus and/or species. It was then possible to assess the distribution of the parasitic groups and the number of genera and/or species associated with each host.

Larvae on Cleome were attacked by a wide range of parasites which included 7 genera whereas tomatoes had 3, maize and sorghum 5, cotton 4 and chickpea 3 genera. By means of a simple ranking system based on a scale of 1-5 (5 different hosts were studied), the monthly total (Appendix 4) for each individual host were ranked in order to show the relative importance and diversity of the parasite's habitat (Table 5).

Table 5. The relative abundance of different species of adult parasites emerging from H. armigera larvae on different host plants during the 1981-82 season.

Parasites	Host plants
HYMENOPTERA	
Braconidae (A.D. Austin det.)	
- <u>Cardiochiles</u> sp. (nr. <u>C. trimaculata</u>) (Cameron)	<u>Cleome</u> ¹ , Cotton ² , Maize ³ , Sorghum ⁴
- <u>Cardiochiles</u> sp	
- <u>Apanteles diparopsidis</u> (Lyle)	Sorghum ¹ , Maize ² , <u>Cleome</u> ³ Cotton ³
Ichneumonidae (I.D. Gauld det.)	
- <u>Charops</u> sp	<u>Cleome</u> ¹ , Chickpea ² , Sorghum ³ Tomato ⁴ , Maize ⁴
- <u>Netelia</u> sp	<u>Cleome</u>
- Other hymenoptera	
'A'	Cotton
DIPTERA	
Tachinidae	
- <u>Palexorista laxa</u> (Curran) (I.M. White det.)	Sorghum ¹ , Cotton ² , Chickpea ³ , <u>Cleome</u> ⁴ , Maize ⁴ , Tomato ⁵
- <u>Paradrino halli</u> (Curran) (K.M. Harris and I.M. White det.)	Chickpea ¹ , <u>Cleome</u> ² , Tomato ²

1 = Most abundant

5 = Least abundant

With the exception of Netelia sp. and species 'A' which only occurred on Cleome and cotton respectively, there was considerable activity between host plants for the parasitic groups. However, Charops sp. and Palexorista laxa (Curran) were the only two parasites recorded on all the different hosts (Table 5). Despite a wide host plant diversity, only a few could be considered common with respect to their relative abundance on the different host plants. Thus, of the 7 different genera recorded on Cleome, only Charops sp. and Cardiochiles spp. were commonly recorded. On maize, only Apanteles diparopsidis (Lyle) was commonly recorded, whereas on sorghum, Charops sp., A. diparopsidis (Lyle) and P. laxa (Curr.) were recorded in large numbers. On cotton, P. laxa (Curr.) and Cardiochiles spp. were equally common; and on chickpea, Charops sp. and Paradrino halli (Curr.) were the commonest.

The general pattern of activity of the different parasitic species was also assessed. Thus, the monthly percentage composition of the species i.e. relative species abundance at a particular time of the year, was calculated from the monthly totals.

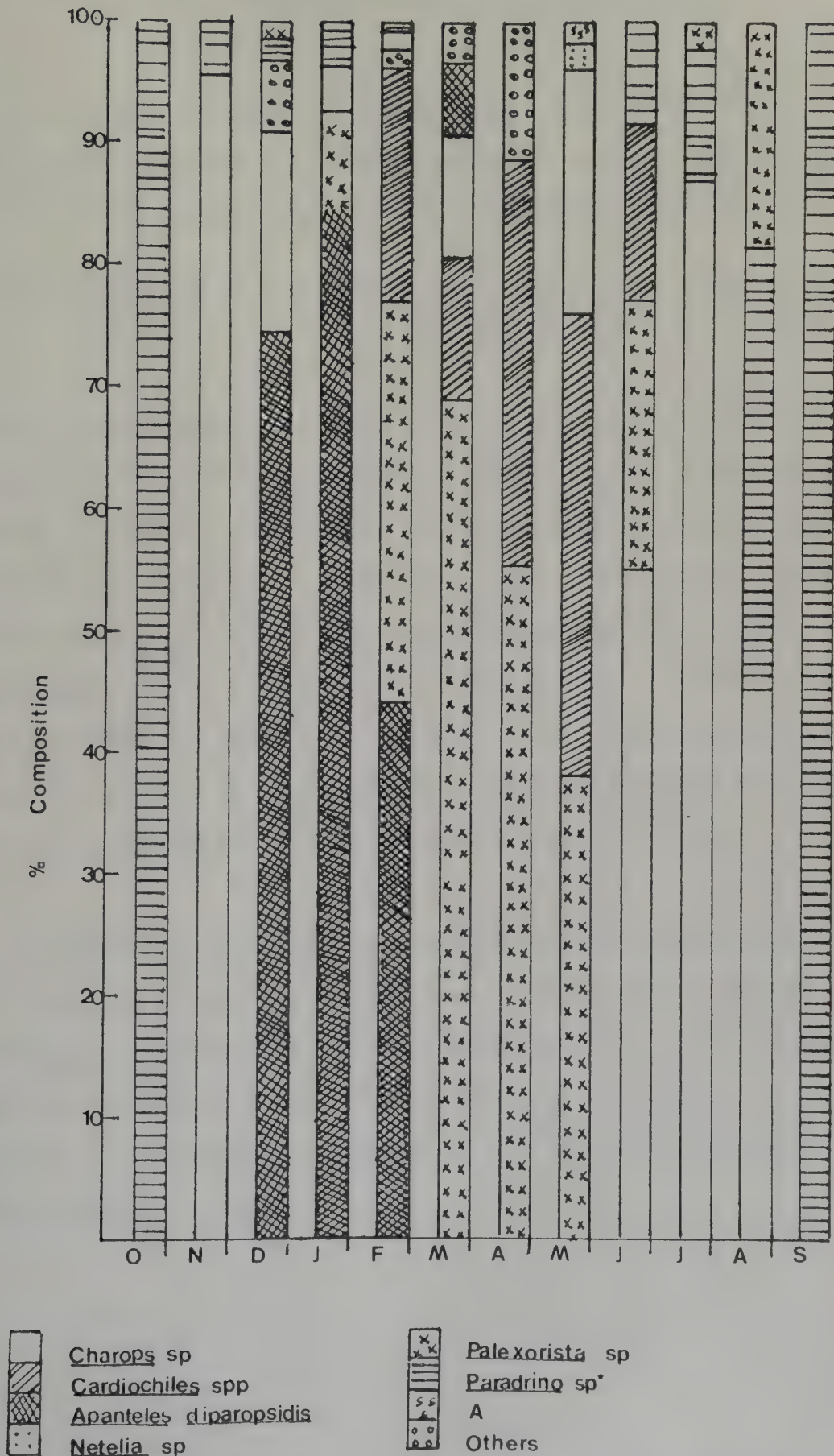
Thus, % composition of species x =

$$\frac{\text{Total number of x in the month}}{\text{Total number of all the different species in that month}} \times 100$$

The data is shown in Figure 16 and gives an indication of the overall activity of the different H. armigera larval parasites in the study area for all the hosts. In Figure 16, P. halli (Curr.) is shown as the most abundant species in October - September but only two specimens were recorded and therefore are possibly rare during that

Fig 16

Percentage composition of emerging adults of different parasitic genera attacking H. armigera larvae collected in the field on all hosts in the Ukiriguru vicinity presented as proportion of monthly totals for all species 1981-82



period. Although larval parasites are available throughout the year only a few species are common at certain times of the year.

It was also possible to establish the relative abundance (the time of the year when the species was most abundant) for all the species. The % relative abundance was calculated as follows:

$$\% \text{ Relative abundance of species X} = \frac{\text{monthly total of X} \times 100}{\text{Annual total for all the species}}$$

The data is summarized in Table 6. During 1981-82 season (Table 6), Charops sp. was active from November to August with peak activity from May to August. The highest record was made in July on larvae collected on chickpea. Cardiochiles spp. were active between February and June with the highest peak in May, whereas A. diparopsidis (Lyle) was available between December and March, with peak activity in January on sorghum. The species pupae were frequently observed on sorghum heads in the field and the adults were also seen searching actively at the pollen stage of the crop.

P. laxa (Curr.) was recorded between December and August with a peak in February-March and again in May. P. halli (Curr.) was active from October to February and June to September with a peak in August, mostly on chickpea. A few other unidentified species, one of which included a multiparasitic Apanteles sp. on larvae collected on sorghum were also recorded.

1981-82 season

1982-83 season[illegible]

Table 6. (Continued)

1983-84 season												
Genera	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
Charops sp	9.0	6.4	27.6	17.0	1.6	2.6	5.3	7.4	2.6	2.6	15.9	1.6
Cardiochiles spp	18.4	17.5	37.2	10.1	2.4	2.8	7.4	4.0	0.0	0.0	0.0	0.0
Apanteles diparopsidis	0.0	0.0	23.6	5.4	0.0	30.9	30.9	9.1	0.0	0.0	0.0	0.0
Microchelonus sp	0.0	0.0	75.0	12.5	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Netelia sp	0.0	0.0	14.3	0.0	0.0	0.0	28.6	57.1	0.0	0.0	0.0	0.0
Pristomerus sp	12.0	4.0	44.0	24.0	0.0	4.0	8.0	4.0	0.0	0.0	0.0	0.0
Palexorista sp	2.9	0.0	0.0	0.0	0.0	0.0	32.3	55.9	2.9	5.9	0.0	0.0
Paradrino sp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0	45.0	30.0	10.0	0.0
A	16.6	27.7	50.0	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C	0.0	0.0	88.3	16.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Apanteles sp (vitripennis group)	0.0	0.0	0.0	0.0	33.3	50.0	16.6	0.0	0.0	0.0	0.0	0.0

1984-85 season												
Genera	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
Charops sp	4.8	3.8	11.6	2.4	3.4	0.5	3.4	3.4	20.8	33.8	12.1	0.0
Cardiochiles spp	6.4	39.9	36.2	5.9	4.6	0.9	2.3	1.4	2.3	0.0	0.0	0.0
Apanteles diparopsidis	0.0	0.0	15.8	56.1	19.5	6.1	1.2	1.2	0.0	0.0	0.0	0.0
Microchelonus sp	0.0	0.0	15.4	46.1	23.1	7.7	0.0	7.7	0.0	0.0	0.0	0.0
Netelia sp	0.0	6.6	33.3	40.0	13.3	0.0	6.6	0.0	0.0	0.0	0.0	0.0
Pristomerus sp	20.6	29.4	32.3	8.8	8.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Palexorista sp	0.0	4.2	8.1	10.4	12.2	6.1	0.0	38.8	6.1	10.2	8.1	0.0
Paradrino sp	0.0	0.0	0.0	6.4	19.1	6.4	0.0	0.0	17.0	34.0	12.7	0.0
A	0.0	36.0	64.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C	0.0	57.1	28.6	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Apanteles sp (vitripennis group)	0.0	2.4	12.2	12.2	4.8	9.7	2.4	12.2	43.9	0.0	0.0	0.0
E	44.4	55.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Meteorus sp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0

Parasitic nematodes were also recorded during the season from larvae collected on Cleome and cotton during May. Only three larvae collected on Cleome were parasitized, and one on cotton, and therefore the parasitic nematodes were not considered important.

4.1.2 1982-83 season general trends

The overall larval mortality for the period October 1982 to September 1983 is shown in Figure 17. Mortality occurred in two peaks. The first peak, which was also the highest, extended between November and February, and this was followed by the second peak between April and June (Fig. 17).

The level of diseased larvae began to build up rapidly from the beginning of the season, reaching peak in January. As in the previous season, pathogens were the main mortality factors (Fig. 17).

Parasitism was generally lower than in the previous season. The early season larval parasitism peak was recorded in November mostly on larvae collected on Cleome and tomatoes. A small peak was recorded in May and June, also observed in 1981-82, mostly on larvae collected on Cleome and chickpea.

The pattern of larval parasitism and diseases in relation to the field levels of infestation on different alternative hosts is shown in Figure 18. As in the 1981-82 season, larval diseases were most important on Cleome (Fig. 18a). Pathogens began to build up gradually from early October reaching a peak in January, and remained

Fig 17 Mortality of *H. armigera* larvae in the Ukiriguru vicinity 1982-83 season presented as total monthly percentages

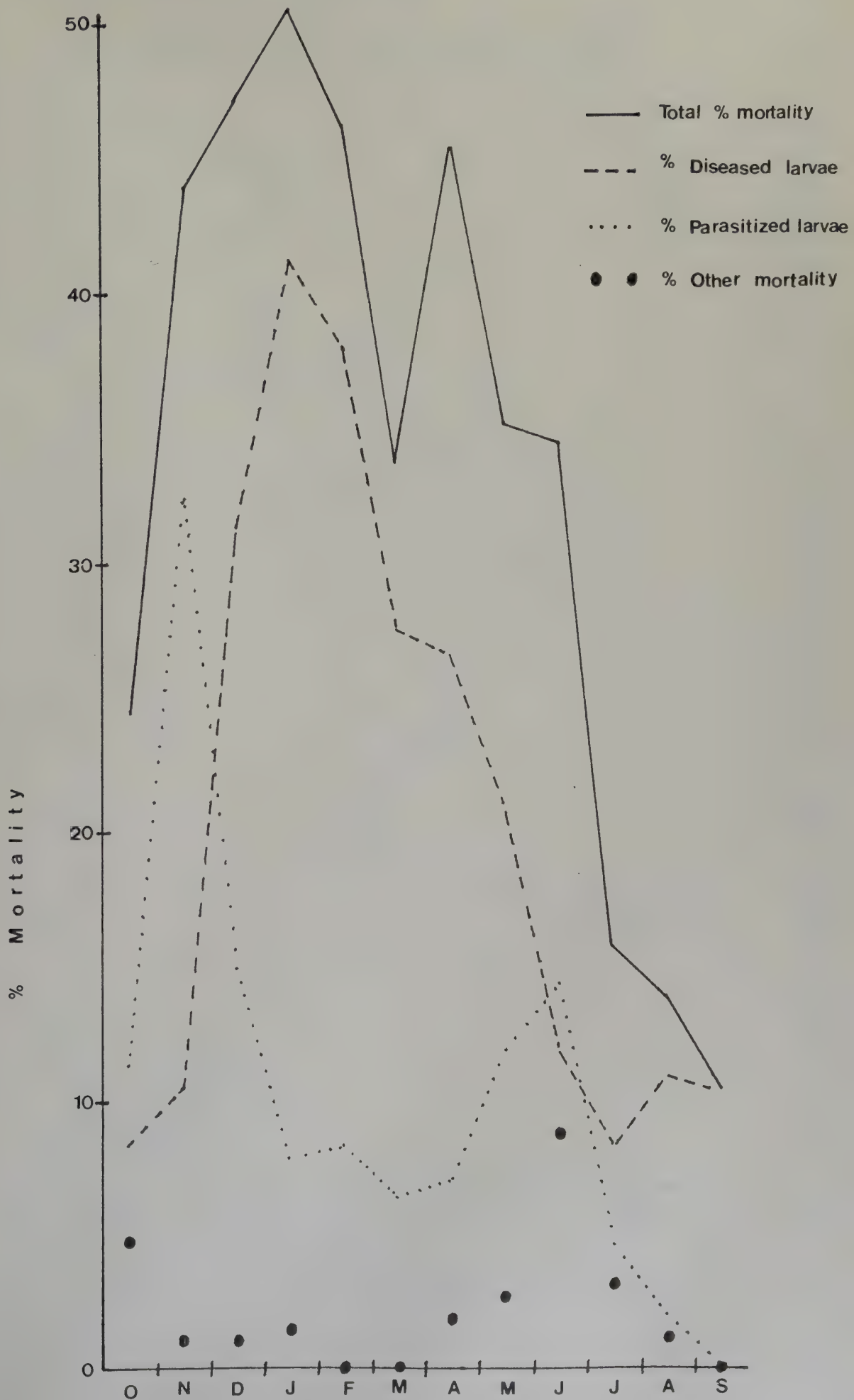


Fig 18 The relationship between the level of infestation and mortality factors (diseases & parasitism) on field collected H. armigera larvae in 1982-83 season presented as weekly means

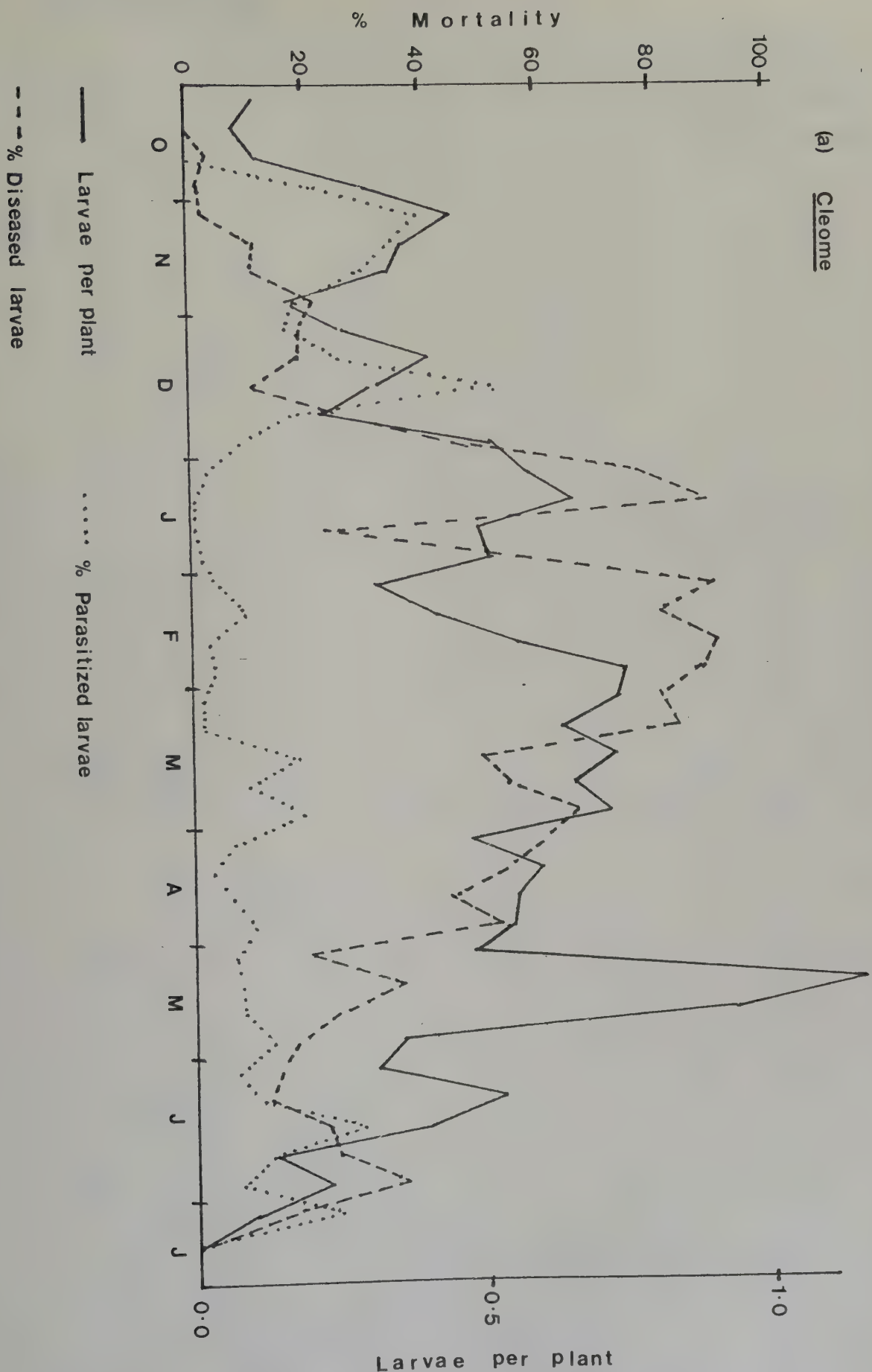


Figure 18 continued
(b) Maize

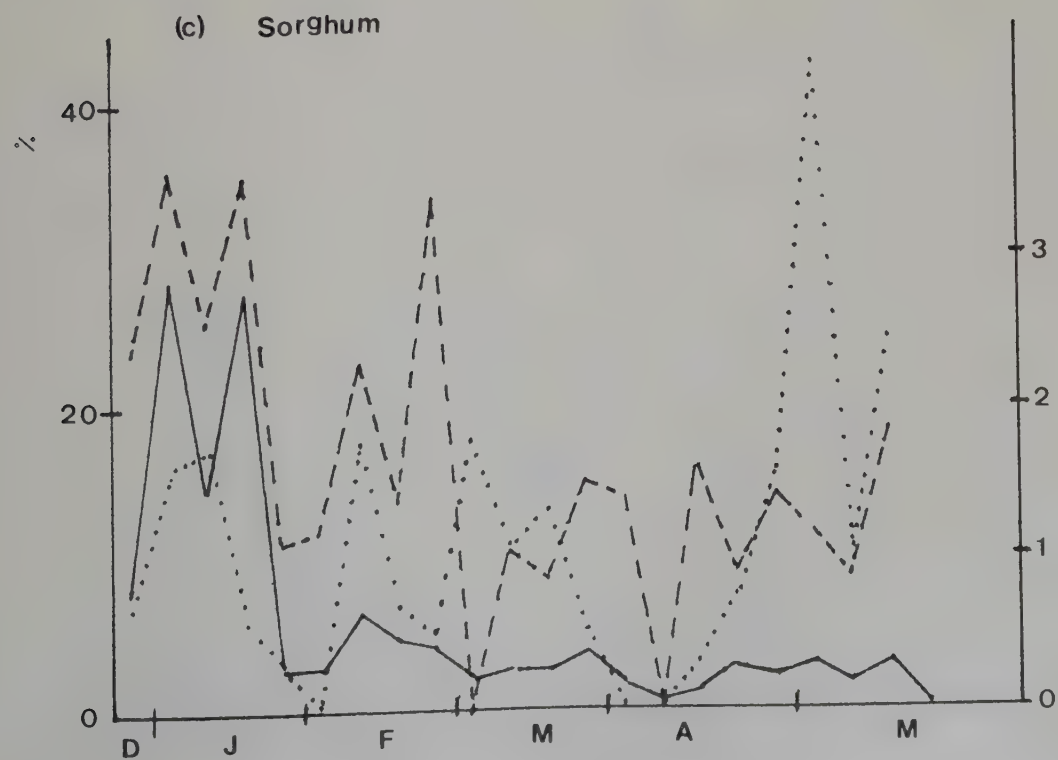
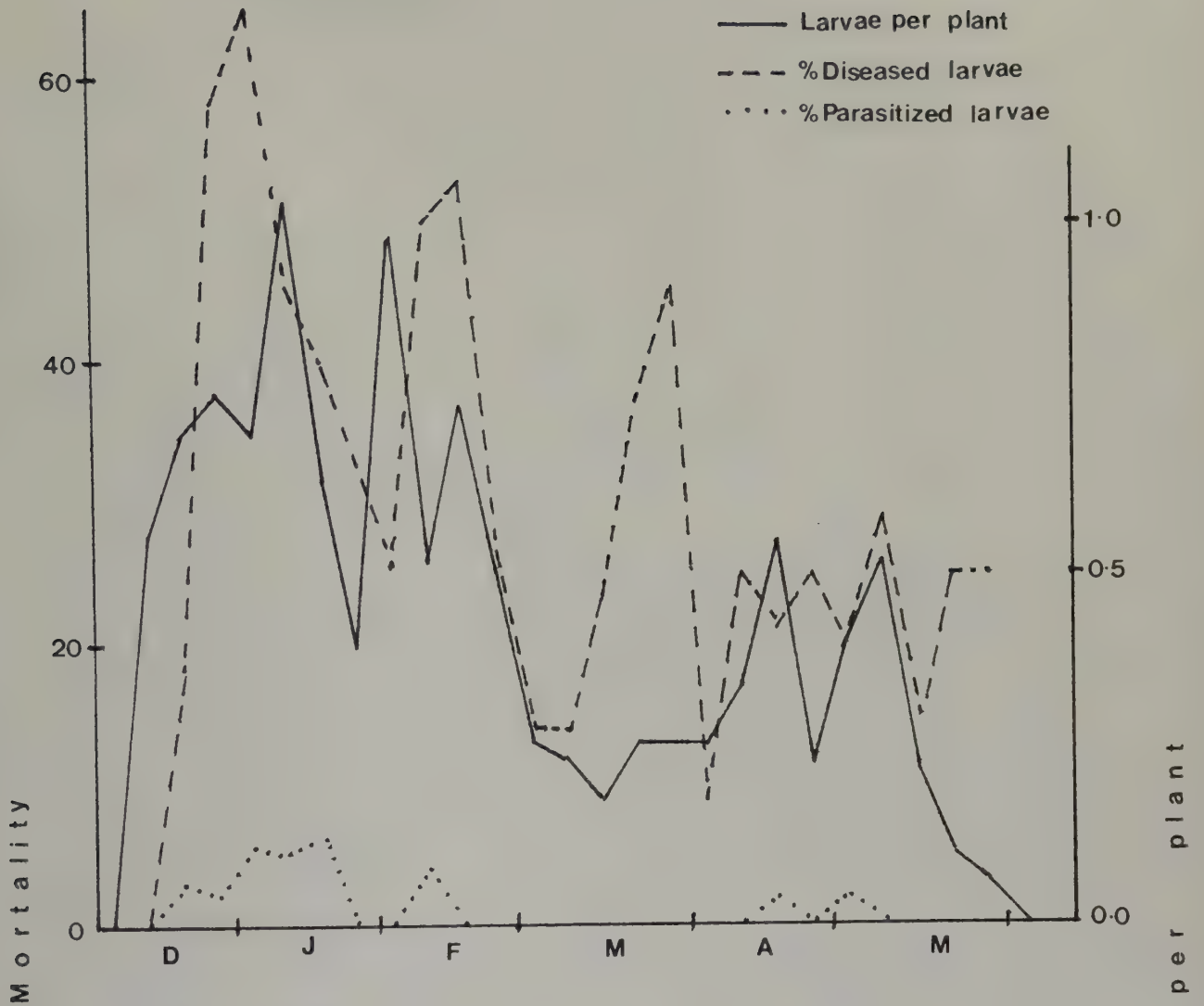


Figure 18 continued

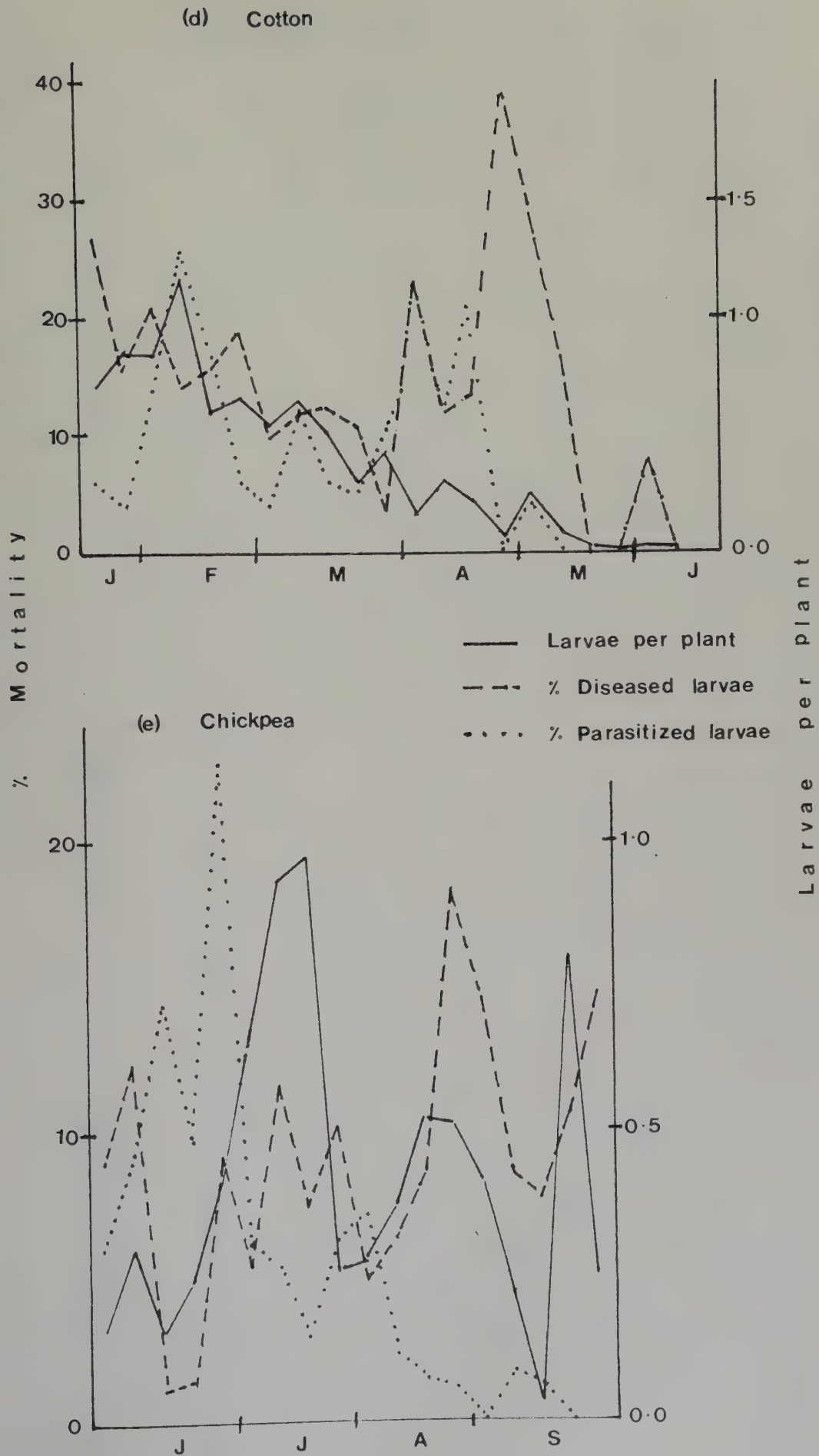
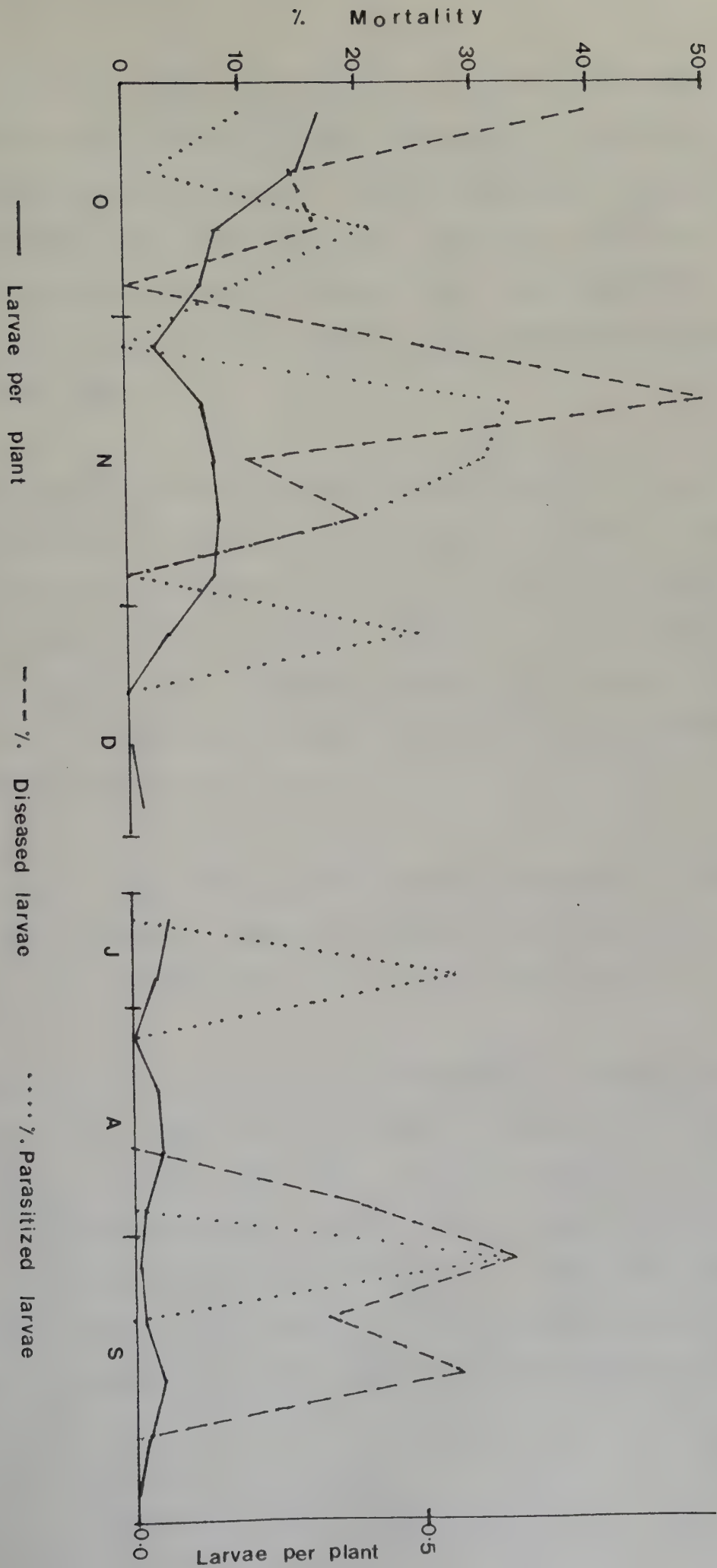


Figure 18 continued

(f) Tomato



at a high level until March, during which time over 50% of the larvae died. Mortality was highest in January and February, an observation also recorded the previous season. Apart from a short period in November-December when high numbers of larvae were parasitized, larval parasitism on Cleome was generally lower than diseases (Fig. 18a). As in previous seasons, there was a late season build up of parasitism on Cleome.

Larval diseases were also a common mortality factor on maize and the percentage level of diseased larvae tended to increase as the level of infestation increased (Fig. 18b). The level of diseased larvae collected on maize increased rapidly as the pest numbers increased, causing over 30% mortality between late December and February. Larval parasitism was again very low, being only about 6% at the peak of parasitism (Fig. 18b).

On sorghum (Fig. 18c), larval diseases were generally more common than parasitism. However, although the level of parasitism was lower than in 1981-82 season, it was higher than on maize.

Similarly, larval diseases were more prevalent on cotton than parasitism and the percent level of diseases increased as the level of infestation increased (Fig. 18d). This relationship was also observed in the previous season. Larval parasitism began to build up in mid January reaching peak in mid-February, two weeks after peak larval numbers on the crop. Overall, the level of larval parasitism remained low throughout the season. There was a late season build up

of parasitism but this occurred when the pest population was declining and therefore were probably of little significance. Diseases however developed earlier in the pest population and possibly reduced the size of the pest population.

The level of both larval diseases and parasites on chickpea was lower compared with the other alternative hosts (Fig. 18e). However, the level of larval parasitism was higher especially early in the season just before the pest population attained its first peak (Fig. 18e). Thus, even on chickpea, the level of parasitism was not high enough to prevent the pest population from building up. Larval diseases became dominant towards the end of the season but its level was low compared with other host plants.

Similarly, larval diseases were a dominant mortality factor on tomatoes (Fig. 18f) especially in October and November. The level of larval parasitism was low but generally higher than in the previous season. Few diseased and parasitized larvae were recorded in August and September.

4.1.2.1 Diseases - During the season, the pattern of distribution of virus and bacterial diseases between the host plants (Table 7 and Fig. 19) was almost similar to the previous season. NPV was far more common on larvae collected from Cleome and maize (Fig. 19a & b) than on the other host plants (Fig. 19c,d & e), although the pathogen was more widespread between the different host plants than in the previous season. NPV was particularly common on larvae collected on

Table 7. Mean monthly summary of the proportion of larvae of H. armigera with viral and/or bacterial infection during 1982-83 season.

Cleome

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Oct	0	100	2
Nov	16.6	83.3	48
Dec	39.0	60.9	105
Jan	78.0	21.9	232
Feb	91.6	8.4	239
Mar	61.6	38.8	162
Apr	53.2	46.8	124
May	43.2	56.7	74
June	28.1	71.8	71
July	0.0	100.0	2
Aug	0.0	0.0	0
Sept	0.0	0.0	0

Maize

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Dec	94.3	5.7	70
Jan	62.2	37.7	302
Feb	42.6	57.3	136
Mar	63.1	36.8	38
Apr	34.6	65.4	26
May	40.5	59.5	42
June	0.0	0.0	0

Sorghum

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Dec	48	52	25
Jan	54.7	45.2	241
Feb	23.8	76.2	42
Mar	0	100.0	11
Apr	19	80.9	21
May	14.3	85.7	21

Table 7 (Continued)

Cotton

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Jan	44.4	55.5	45
Feb	37.3	62.6	83
Mar	56.6	63.8	47
Apr	54.5	64.7	17
May	12.5	87.5	8

Chickpea

Month	% Virus	% Bacteria	Total Number of Diseased larvae
June	22.6	77.4	31
July	30.9	69.0	168
Aug	11.8	88.1	118
Sept	31.8	68.2	44

Tomato

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Oct	0	100	12
Nov	40.0	60.0	10

Fig19 Mean monthly % mortality due to virus and bacteria on *H. armigera* field collected larvae and observed in the insectary during 1982-83 season

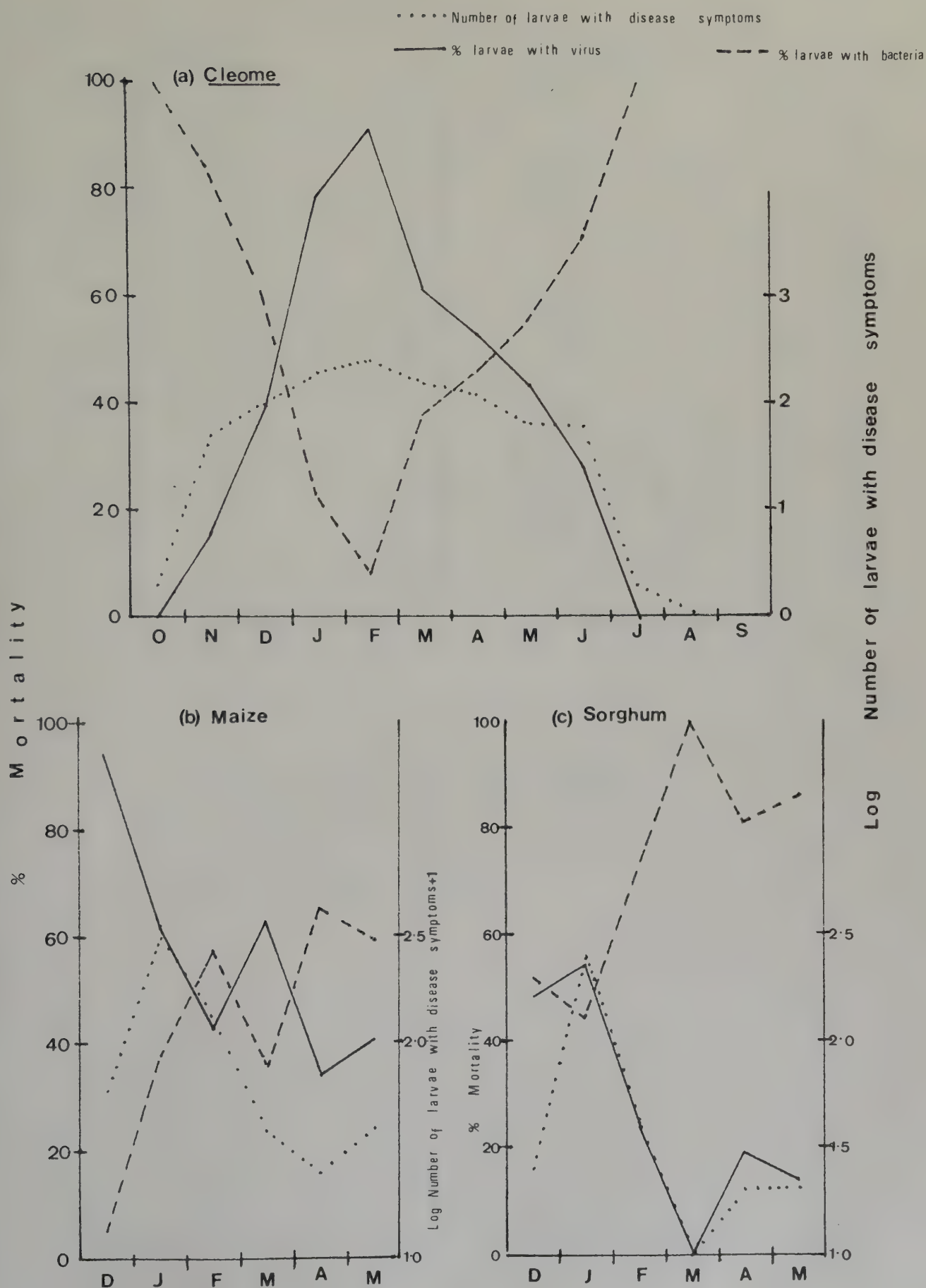
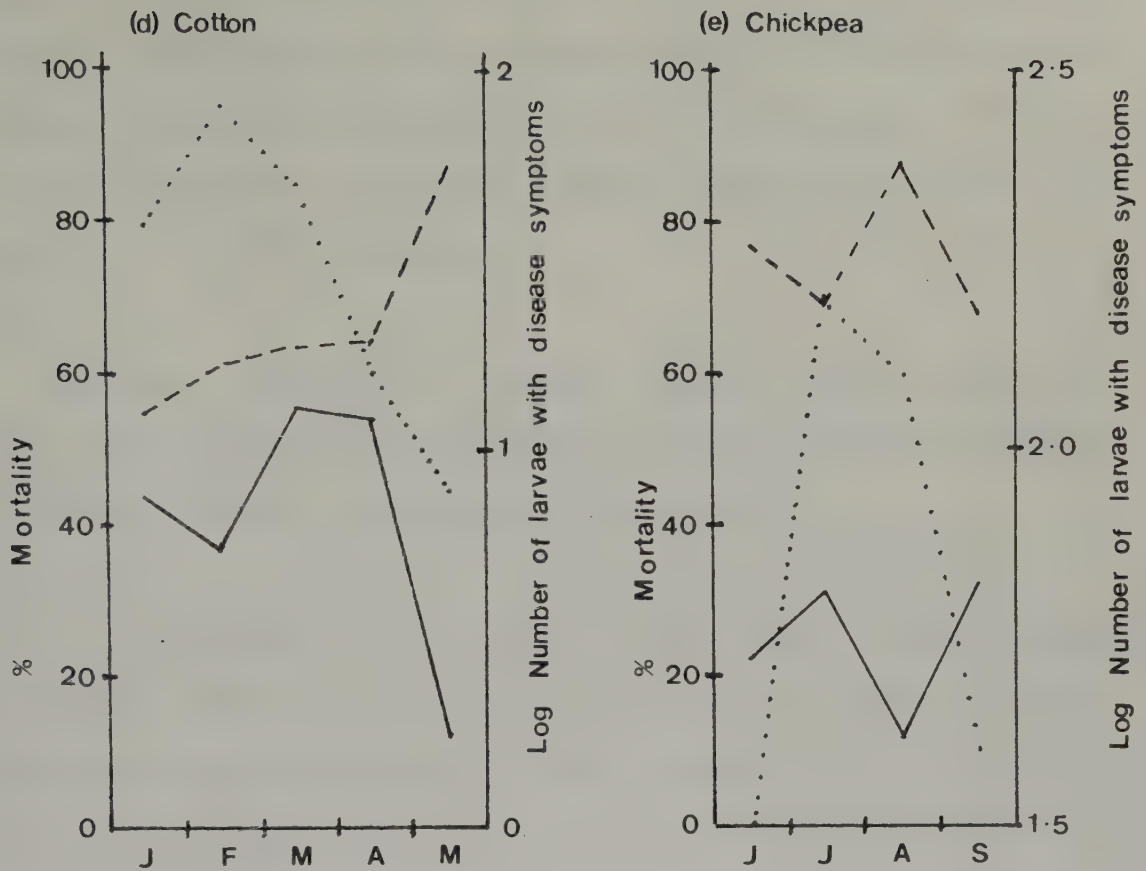


Figure 19 continued



..... Number of larvae with disease symptoms

— % Larvae with virus

--- % Larvae with bacteria

Cleome between January and March, an observation also made last season. Similarly, few of the larvae collected from maize between December and March survived due to high virus infection. The level of NPV on the other alternative hosts was comparatively low as was observed in the 1981-82 season.

Bacterial diseases, as in the previous season, were more widespread between the host plants but were most prevalent on larvae collected on chickpea, sorghum, cotton and tomatoes.

4.1.2.2 Parasites - H. armigera larval parasites were active throughout the year (Table 6) but the level and number of species involved varied between the host plants (Table 8 and Appendix 4) and also with time (Fig. 20).

Comparison with the current season showed that more parasite genera were recorded in 1982-83. This season, 10 genera were recorded compared with 7 in the previous year. Eight were recorded on Cleome, 5 on tomatoes, sorghum and chickpea, 6 on maize and 7 on cotton (Table 6).

The overall distribution of the different parasites on the H. armigera hosts is summarized in Table 8. Apart from Pristomerus sp. and Meteorus sp. which were restricted only to Cleome and cotton respectively, there was inter-host plant diversity for the majority of the parasites. However, despite this fact, only a few could be considered important on any host plant. Thus, on Cleome, Charops sp.

Table 8. The relative abundance of different species of adult parasites emerging from H. armigera larvae on different host plants during the 1982-83 season.

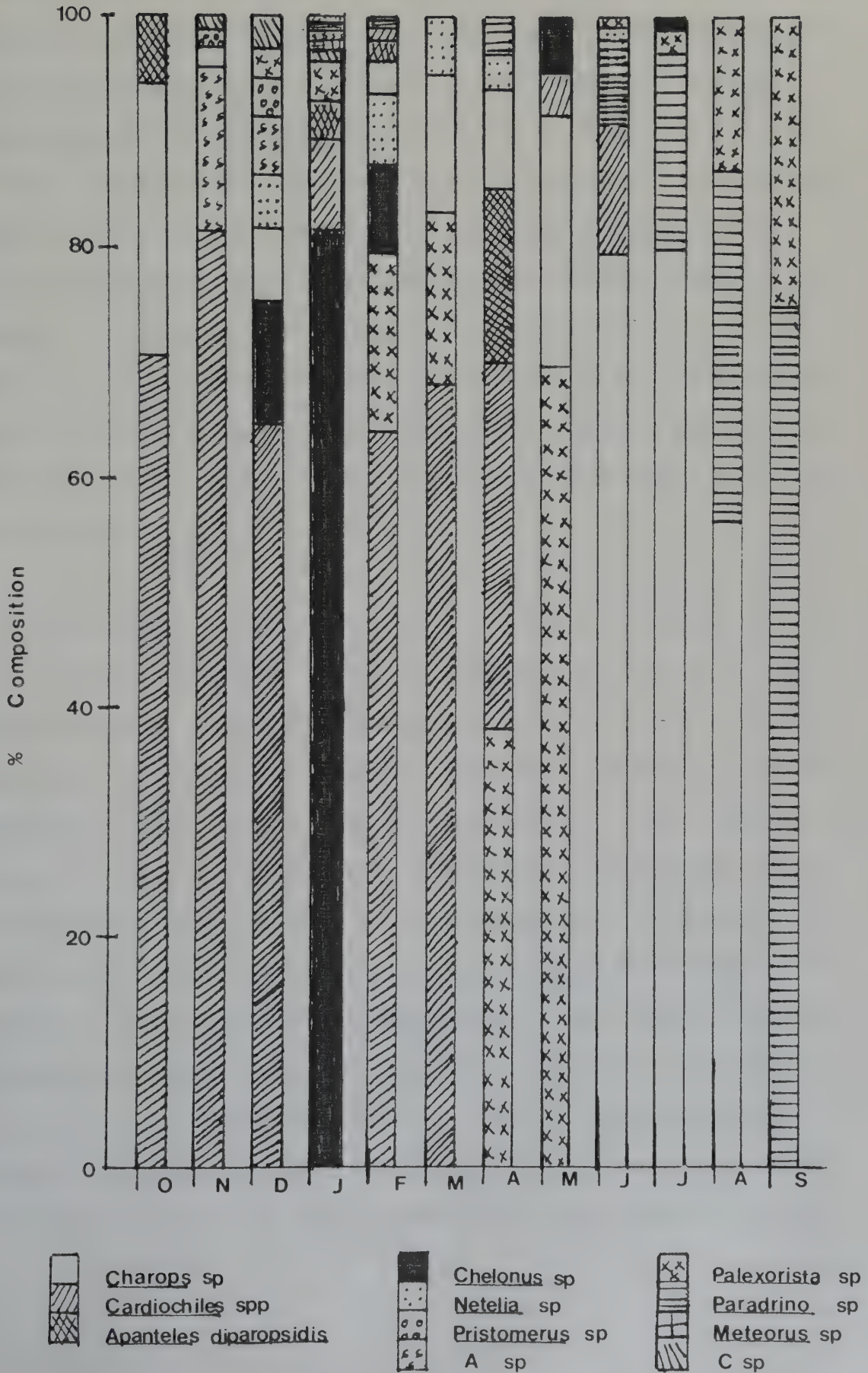
Parasite	Host Plants
HYMENOPTERA	
Braconidae	
- <u>C. sp</u> (nr. <u>C. trimaculata</u>)) <u>Cleome</u> ¹ , Cotton ² , Tomato ³ , Maize ⁴ ,
- <u>Cardiochiles</u> sp) Chickpea ⁵
- <u>C. (Microchelonus) curvimaculatus</u>	Sorghum ¹ , Maize ² , Cotton ³ , Chickpea ⁵ , <u>Cleome</u> ⁴
- <u>A. diparopsidis</u>	Sorghum ¹ , Maize ² , Cotton ³ , Tomato ³ , <u>Cleome</u> ³
- <u>Meteorus</u> sp	Cotton
Ichneumonidae	
- <u>Charops</u> sp	Chickpea ¹ , <u>Cleome</u> ² , Tomato ³ , Cotton ⁴ , Maize ⁵
- <u>Netelia</u> sp	Sorghum ¹ , Maize ² , <u>Cleome</u> ³
- <u>Pristomerus</u> sp	<u>Cleome</u>
Other hymenoptera	
A	<u>Cleome</u> ¹ , Tomato ²
C	<u>Cleome</u> ¹ , Tomato ²
DIPTERA	
Tachinidae	
- <u>P. halli</u>	Chickpea ¹ , Cotton ²
- <u>P. laxa</u>	Sorghum ¹ , Chickpea ² , Cotton ³ , Maize ⁴

One case of a multiparasitic Apanteles sp. was recorded on larvae collected from sorghum.

1 = most abundant

5 = least abundant

Fig 20 Percentage composition of emerging adults of different parasitic genera attacking H. armigera larvae collected in the field on all hosts in the Ukiriguru vicinity presented as proportion of monthly totals for all species - 1982-83 season



and Cardiochiles spp. were highly active and were recorded in large numbers. These two parasites were also recorded in large numbers on Cleome the previous season. On maize, only C. (Microchelonus) curvimaculatus (Cam.) was commonly recorded, whereas on sorghum, C. (Microchelonus) curvimaculatus (Cam.) and P. laxa (Curr.) were commonly recorded. P. laxa (Curr.) was also commonly recorded on sorghum in the previous season. The commonest parasites on cotton were Cardiochiles spp. also recorded last season, whereas on chickpea, Charops sp. and P. halli (Curr.) were available in high numbers, an observation also made last season. As in 1981-82, there was no particular parasite species that was particularly important on tomatoes although several genera were recorded from larvae collected on this host.

The overall pattern of activity of the different parasitic groups for all the host plants is summarized in Fig. 20. Thus, larval parasites were available throughout the year and in any one particular month, several species were active but their level of abundance varied. The seasonal abundance for each individual parasite (Table 6) showed that Charops sp. was active almost throughout the year with peak activity during June and July when it was recorded mostly from larvae collected on Cleome and chickpea. In contrast to last season when the Cardiochiles spp. were active only between February and July, these parasite species were recorded from the beginning of October to the end of June. Peak activity was in November on larvae collected from Cleome and in February on larvae collected on cotton. A. diparopsidis (Lyle) was generally recorded

in low numbers on all the host plants and was therefore a minor parasite. In contrast, in the previous season this species was relatively abundant and was recorded as one of the most common larvae parasites on sorghum.

C. (Microchelonus) curvimaculatus (Cam.) was recorded for the first time during the 1982-83 season, large numbers being recorded from larvae on sorghum in January. Netelia sp. was again recorded in only small numbers and was therefore not considered an important larval parasite on any of the host plants.

Pristomerus sp. was also a new record, and the species was active early in the season during November and December. P. laxa (Curr.) was active from December to September with a peak in May when large numbers were recorded on larvae collected on sorghum. Last season, the parasite was also available in large numbers on sorghum during May. P. halli (Curr.) was less abundant during the season compared to 1981-82, but attained peak activity on chickpea also between June and August.

Parasitic nematodes were recorded from larvae on Cleome and cotton. Although the overall level of larval mortality caused by the nematodes was very low, there were more parasitised larvae between mid November and May than in the previous season.

4.1.3 1983-84 season general trends

The overall pattern of larval mortality is summarized in Figs.

Fig 21 Mortality of *H. armigera* larvae in the Ukiriguru vicinity 1983-84 season presented as total monthly percentages

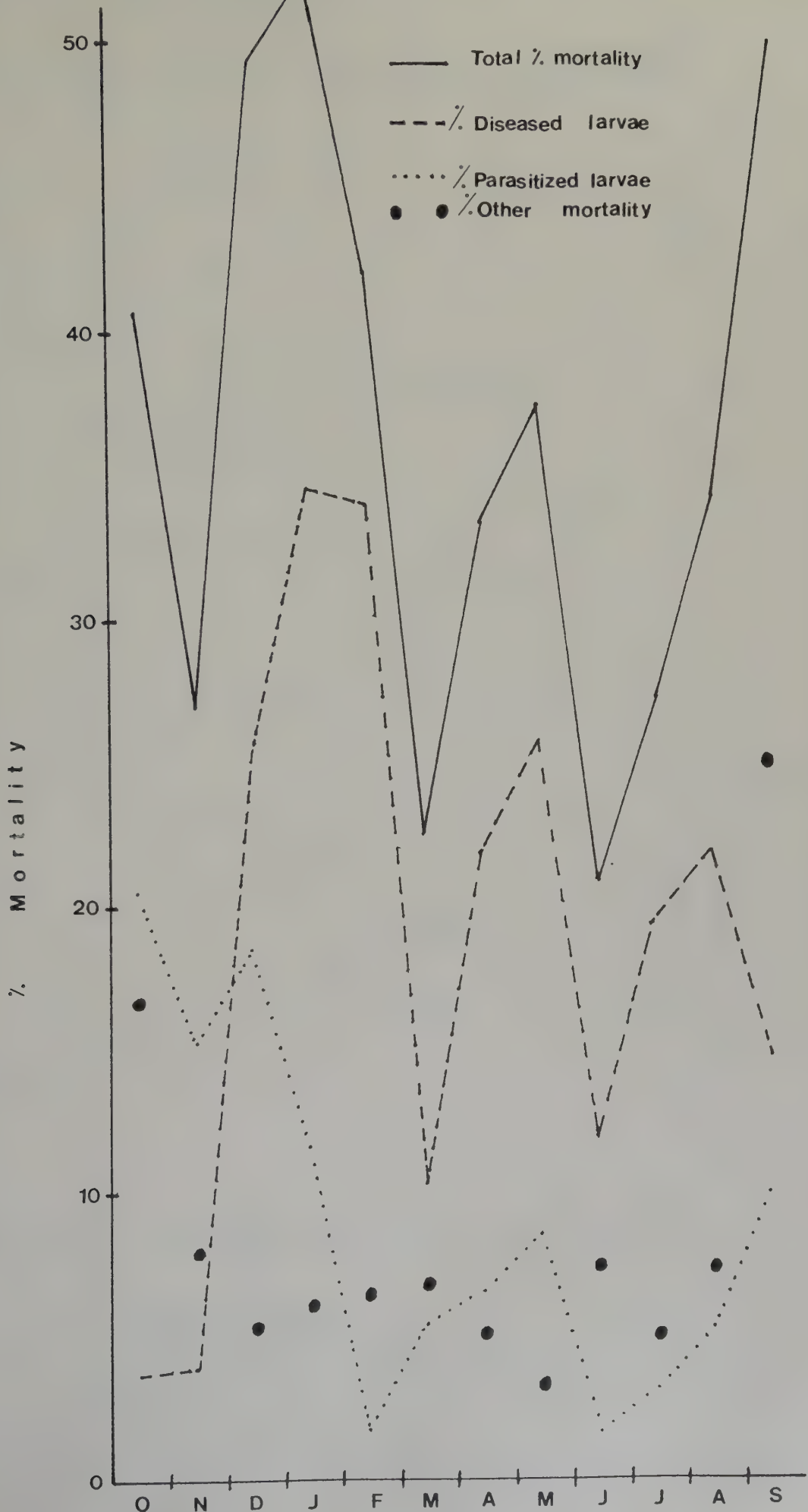


Fig 22 The relationship between the level of infestation and mortality factors (diseases & parasitism) on field collected H. armigera larvae in 1983-84 season presented as weekly means

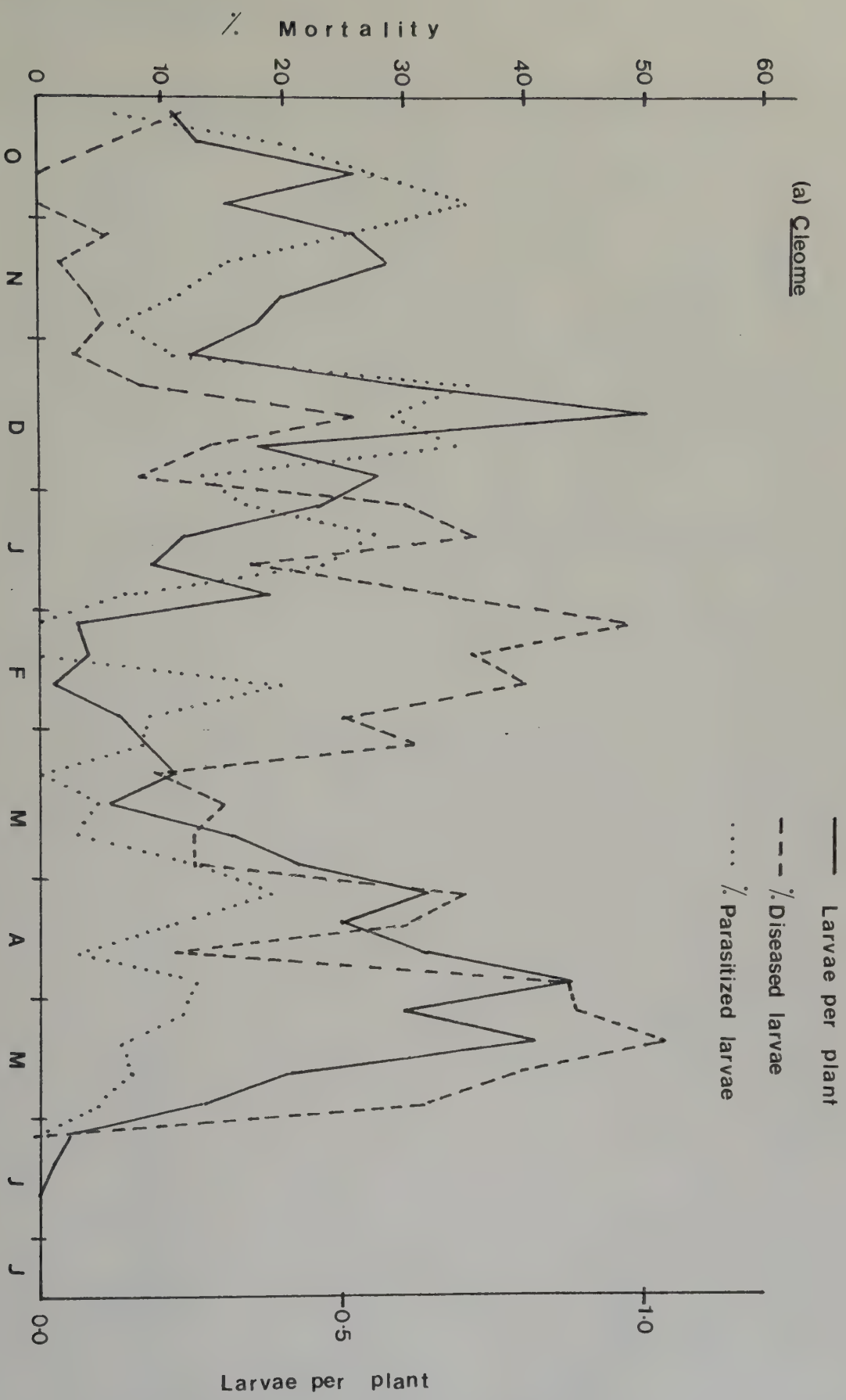


Figure 22 continued

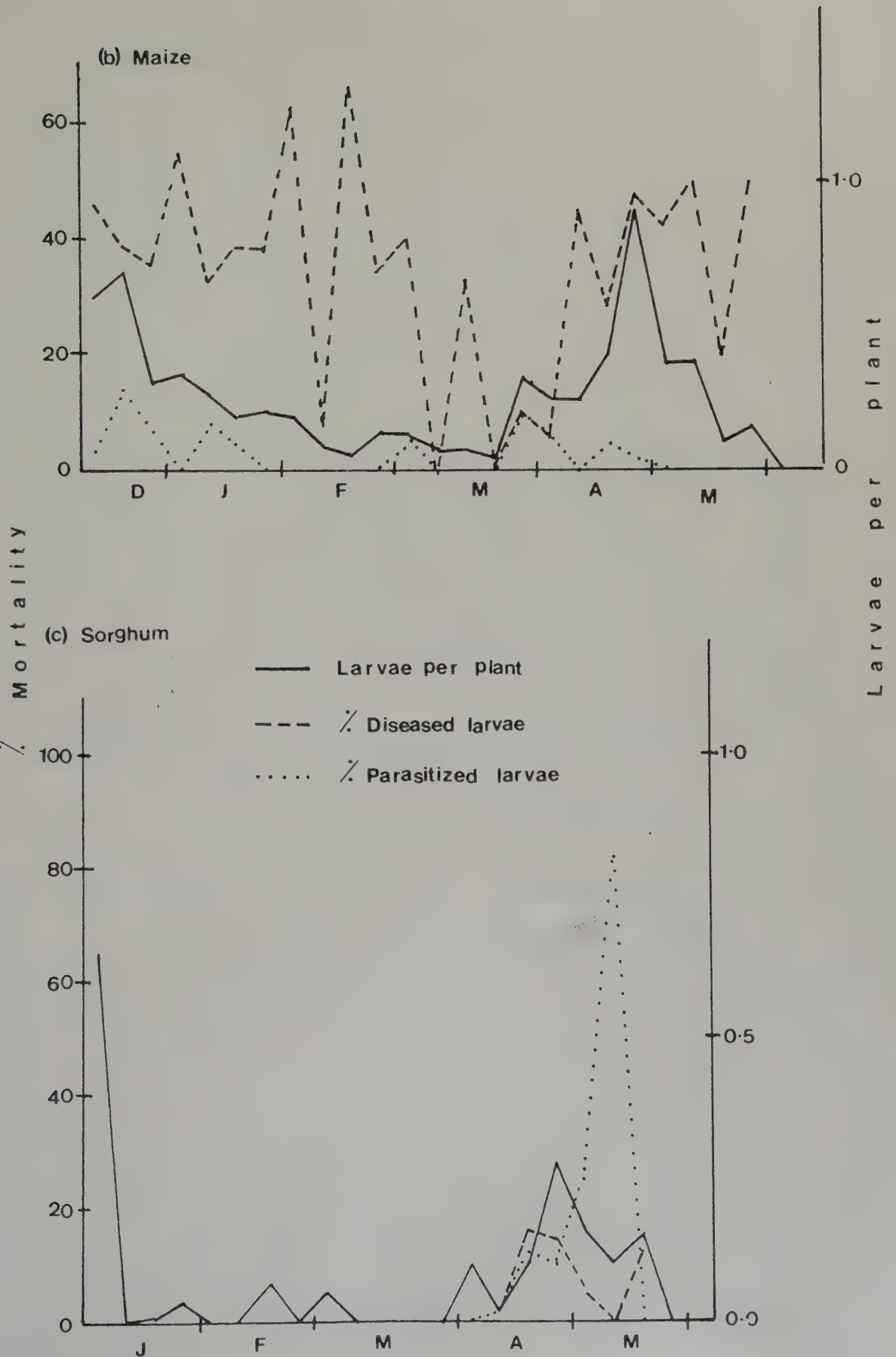
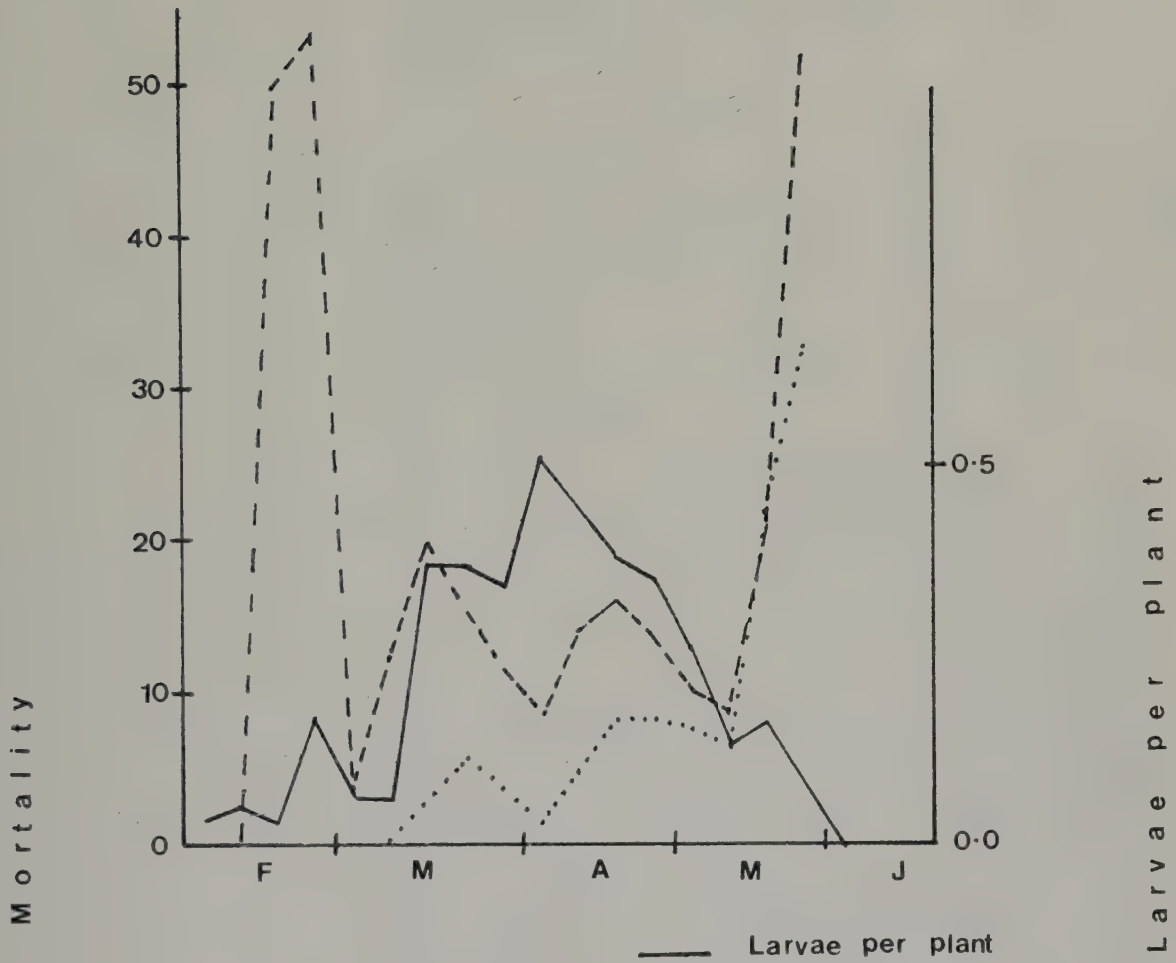


Figure 22 continued

(d) Cotton



(e) Chickpea

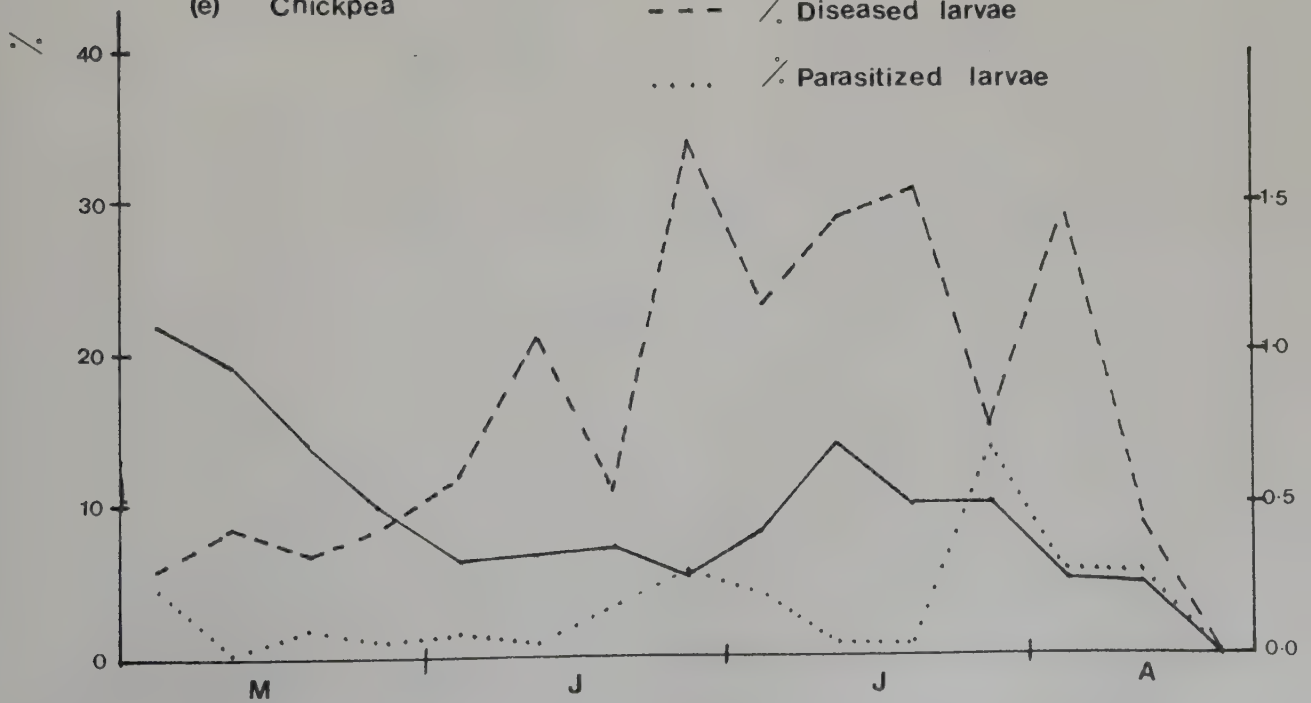
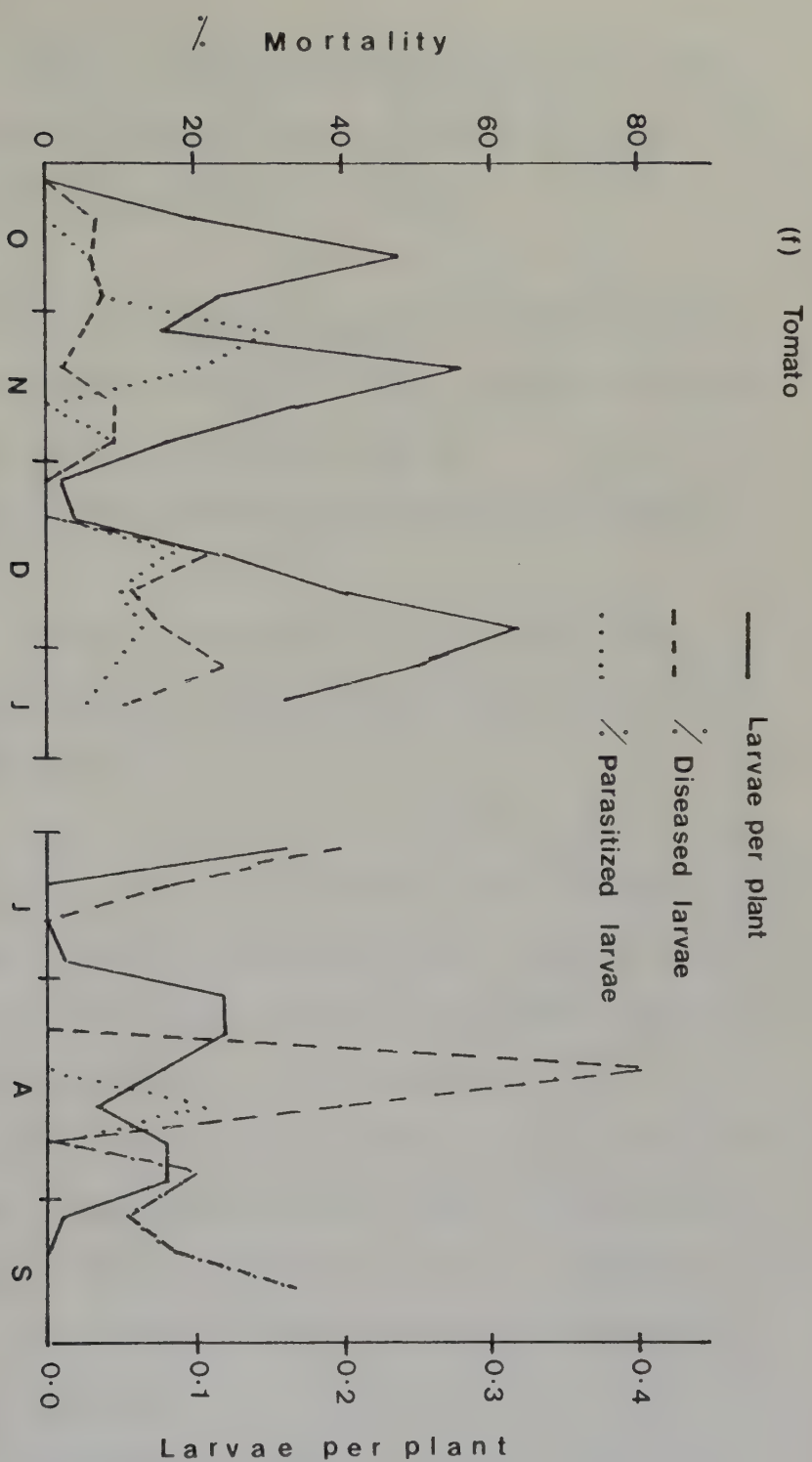


Figure 22 continued



21 and 22. Apart from the period October-December when larval parasitism was a prevalent mortality factor, diseases were again the major cause of mortality during most of the season.

Between October and early December Cleome and tomatoes were the main sources of diseased larvae (Fig. 22a and f), after which maize became the main source up to early March (Fig. 22b). The level of diseases in the overall population began to decline in mid February.

The late season increase in the mortality of larvae (Fig. 21) was mainly due to an unknown disease which occurred on larvae collected from chickpea (Fig. 22e).

The relative abundance of larval parasites and pathogens on Cleome (Fig. 22a) was different to previous years. Although larval diseases began to build up on Cleome early in the season, pathogens remained less important compared to parasitism until the end of December. Diseases became prevalent from January to the end of the season, with the highest peak being recorded in May. A large number of larvae died between January and February due to diseases as occurred in the past two seasons. However, the pattern and level of larval parasitism was different. Larval parasites were relatively more important than diseases from October to December, and although fewer parasitized larvae were recorded thereafter, the level of parasitism was higher than reported in the previous two seasons.

On maize, larval diseases continued to be a dominant mortality

factor in comparison to parasitism (Fig. 22b). Diseases began to build up early in the season and remained at a high level to the end of February (Fig. 22b). As noted in previous seasons, the intensity of disease was possibly correlated to larval density. The level of parasitism was low compared to other alternative host plants but was generally higher than has been observed in previous seasons.

The H. armigera larval population on sorghum was low and discontinuous as was the pattern of mortality (Fig. 22c), and although diseased larvae were more common than those parasitised, both mortality factors occurred at lower levels than has been observed in previous seasons.

Similarly, the level of larval parasitism and diseases were very low on cotton (Fig. 22d). Although diseased larvae were more frequent than those which were parasitised, the overall effect on the pest population may have been negligible. As recorded previously, the level of parasitism tended to build up towards the end of the season at a time when the pest population was already declining (Fig. 22d).

The overall level of diseases was relatively low on chickpea during the season compared to other alternative hosts, but was generally higher than has been found in previous seasons in particular between June and August (Fig. 22e). The level of parasitism was again rather low and tended to build up towards the end of the season at a time when the level of infestation was declining.

On tomatoes, Fig. 22f, except for a short period in November when parasitised larvae were recorded in greater numbers than diseased larvae, larval mortality was mainly due to diseases.

4.1.3.1 Diseases - Mortality due to viral and bacterial diseases on the different host plants is summarised in Table 9 and Figure 23. Overall, bacterial diseases were more common than viral diseases. NPV was again important and was recorded more on larvae collected on Cleome and maize than the other host plants, an observation also made in previous seasons.

4.1.3.2 Parasitism - H. armigera larval parasites were active throughout the season but the level and abundance (Appendix 4) of the species varied in time (Table 6) and space (Table 10), also reported in previous seasons. Overall, 10 genera, comprising 13 species, were recorded. Cleome was again the richest and was associated with 9 genera, tomatoes 6, maize 5, sorghum 7, cotton 6 and chickpea 3.

The pattern of their distribution on the different alternative hosts is summarized in Table 10. Apart from C. (Microchelonus) curvimaculatus (Cam.) and A. sp. (vitripennis sp. group) which were recorded only on Cleome, most of the other parasites had a diverse plant host affinity. However, as in previous seasons, only a few of the parasites could be considered important on Cleome whereas, on maize, only A. diparopsidis (Lyle) was recorded in large numbers. P. laxa (Curran) was the only species recorded in large numbers on sorghum, whereas Cardiochiles spp. and A. diparopsidis (Lyle) were

Table 9. Mean monthly summary of the proportion of larvae of H. armigera with viral and/or bacterial infection during 1983-84 season

Cleome

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Oct	100.0	0.0	7
Nov	0.0	100.0	24
Dec	34.7	65.3	144
Jan	46.8	53.1	96
Feb	42.8	57.6	33
Mar	8.1	91.9	37
Apr	44.0	55.9	134
May	51.1	48.8	133
June	0.0	0.0	0
July	0.0	0.0	0
Aug	0.0	0.0	0
Sept	0.0	0.0	0

Maize

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Dec	54.5	45.4	176
Jan	47.2	52.7	91
Feb	56.7	63.2	49
Mar	33.3	66.6	12
Apr	34.0	66.0	50
May	69.8	30.2	53

Sorghum

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Jan	50.0	50.0	2
Feb	0.0	100.0	1
Mar	50.0	50.0	2
Apr	20.0	80.0	30
May	14.3	85.7	7

Table 9. (Continued)

Cotton

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Feb	50.0	50.0	4
Mar	37.1	62.8	35
Apr	30.0	70.0	20
May	7.7	92.3	13

Chickpea

Month	% Virus	% Bacteria	Total Number of Diseased larvae
May	33.3	66.6	9
June	45.1	54.9	51
July	53.9	46.0	76
Aug	39.7	60.3	121

Tomato

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Oct	100.0	0.0	8
Nov	14.3	85.7	7
Dec	31.8	68.2	22
Jan	38.4	61.5	13
Aug	16.6	83.3	12
Sept	33.3	66.6	3

Fig 23 Mean monthly % mortality due to virus and bacteria on *H. armigera* field collected larvae and observed in the insectary during 1983-84 season

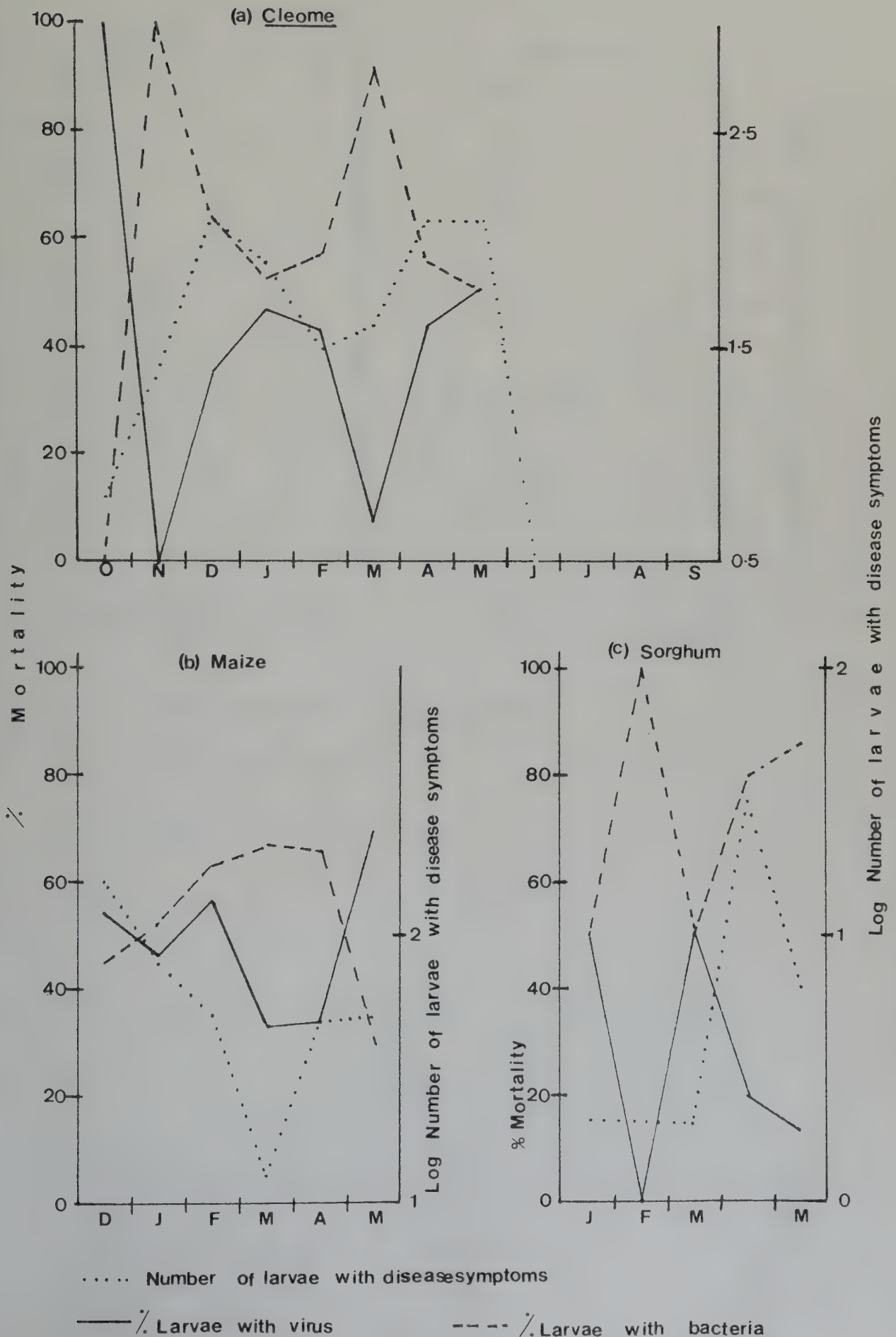


Figure 23 continued

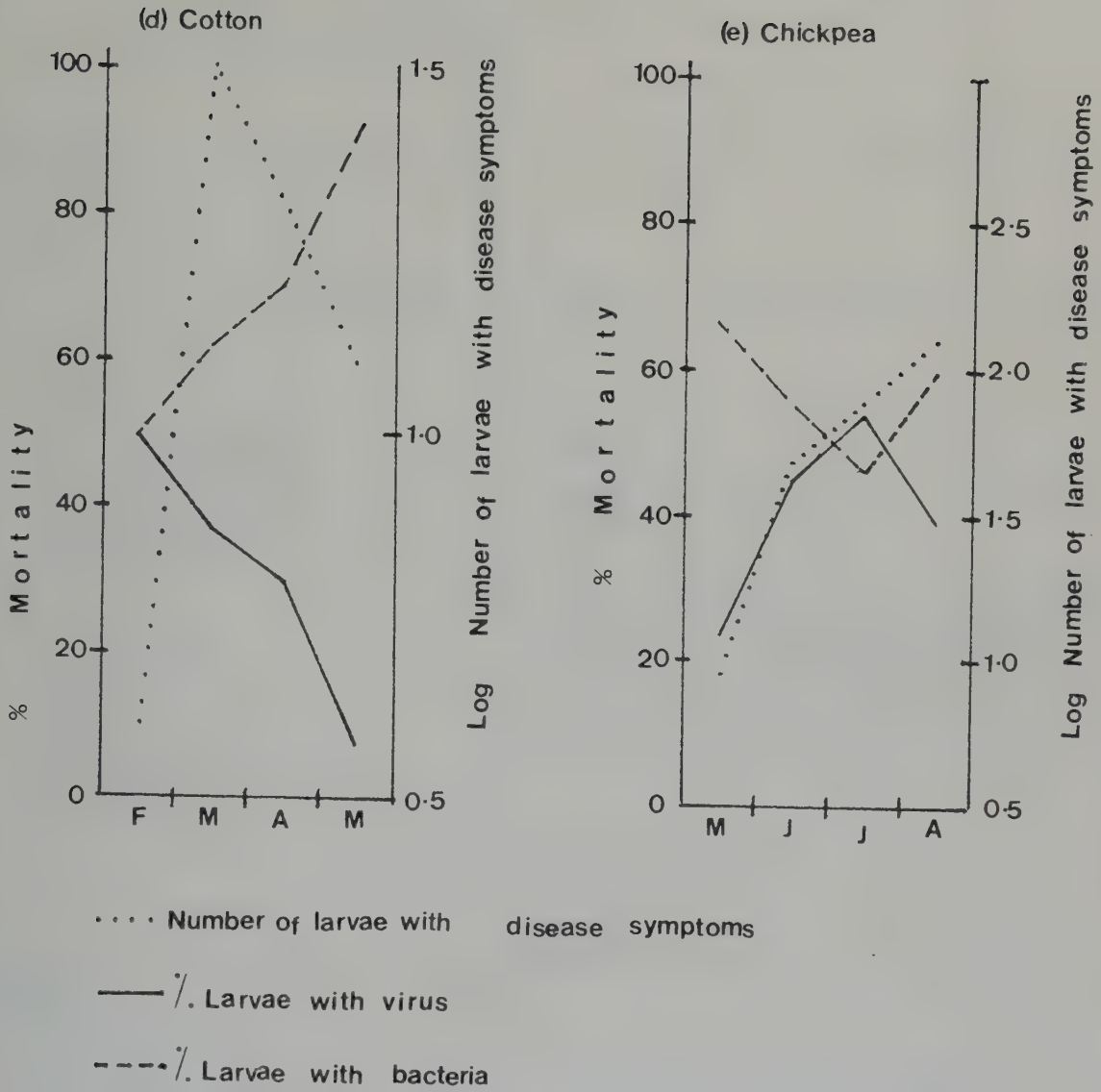


Table 10. The relative abundance of different species of adult parasites emerging from H. armigera larvae on different host plants during the 1983-84 season

Parasite	Host plants
HYMENOPTERA	
Braconidae	
- <u>C. sp</u> (nr. <u>C. trimaculata</u>)] <u>Cleome</u> ¹ , Tomato ² , Cotton ³ , Maize ⁴ , Sorghum ⁵
- <u>Cardiochiles</u> sp	
- <u>C. (Microchelonus) curvimaculatus</u>	<u>Cleome</u>
- <u>A. diparopsidis</u>	<u>Cleome</u> ¹ , Maize ² , Cotton ³ , Sorghum ⁴
- <u>A. sp (vitripennis sp. group)</u>	<u>Cleome</u>
Ichneumonidae	
- <u>Charops</u> sp	<u>Cleome</u> ¹ , Chickpea ² , Tomatoes ³ , Cotton ⁴ Maize ⁵ , Sorghum ⁵
- <u>Netelia</u> sp	Sorghum ¹ , <u>Cleome</u> ² , Tomato ² , Cotton ²
- <u>Pristomerus</u> sp	<u>Cleome</u> ¹ , Tomato ² , Maize ² , Sorghum ² , Cotton ³
Other hymenoptera	
A	<u>Cleome</u> ¹ , Tomato ²
C	<u>Cleome</u> ¹ , Maize ²
DIPTERA	
Tachinidae	
- <u>P. halli</u>	Chickpea ¹ , Sorghum ² , Tomato ²
- <u>P. laxa</u>	Sorghum ¹ , Cotton ² , Chickpea ³ , <u>Cleome</u> ⁴

One case of a multiparasitic Apanteles sp. was recorded on a larva collected from Cleome.

1 = most abundant

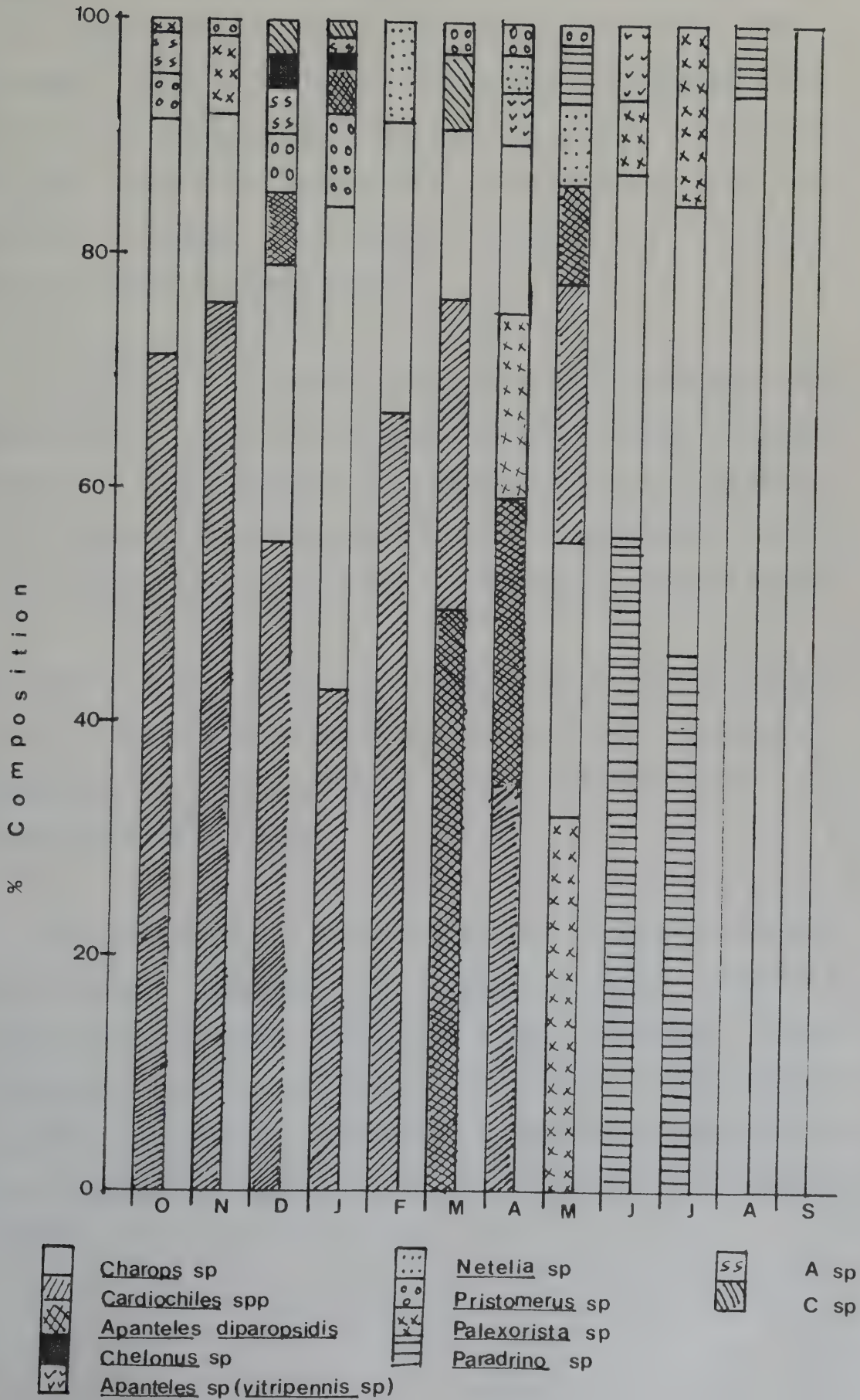
5 = least abundant

common on cotton. On chickpea, Charops sp. and P. halli (Curran) were recorded in large numbers but were less abundant than had been observed in previous seasons. Charops sp. and Cardiochiles spp. were recorded on larvae collected on tomato in relatively larger numbers than has been observed previously. In general, the abundance of larval parasites was considerably lower than in previous seasons.

The overall pattern of activity of the different parasites for all the different hosts is shown in Figure 24. Although the figure shows continuous larval parasitism throughout the season, only one larva was recorded with a Charops sp. parasite in September. In addition, only a few of the species were active in large numbers despite the fact that at any one month several species were active.

The seasonal abundance of the different parasite species during the season is summarized in Table 6. Overall, the majority of the parasites were active over a shorter period than in most seasons. Charops sp. was the only species recorded throughout the season, with a peak in December and January on larvae collected from Cleome, and in August on chickpea. Cardiochiles spp. were recorded from October to May, with peak numbers in October and December on larvae collected from Cleome. A. diparopsidis (Lyle) was recorded from December to May with a peak of activity in December, mostly on larvae collected in maize, and in March and April on larvae collected from Cleome and cotton. A. sp. (vitripennis sp. group) was recorded from February to April, attaining peak in March on larvae collected from Cleome. C. (Microchelonus) curvimaculatus (Cameron) was recorded from December

Fig 24 Percentage composition of emerging adults of different parasitic genera attacking *H. armigera* larvae collected in the field on all hosts in the Ukiriguru vicinity presented as proportion of monthly totals for all species - 1983-84 season



to February, with peak activity in December on larvae collected on Cleome. The occurrence of Netelia sp. was rather sporadic and was again recorded in very low numbers and could not therefore be considered common on any of the host plants. Pristomerus sp. was active over a longer period of time than last season and was recorded in large numbers in December and January, mostly from larvae collected on Cleome. Last season the species was recorded from larvae collected on Cleome alone.

In contrast to previous seasons, the tachinids were late season parasites. P. halli (Curran) was active between May and August, mostly on chickpea, whereas P. laxa (Curran) was active from April to July, largely on larvae collected from cotton and sorghum. Overall, the two parasite species were less abundant than in previous seasons.

The 'A' species was recorded from the beginning of the season to January with peak activity in November on larvae collected from Cleome; whereas 'C' was recorded in December and January, mostly from larvae collected on Cleome.

The level of larval parasitic nematodes in the pest population was very low. Nematodes were recorded from larvae collected in Cleome between November and May with a peak in November - December when the average level of parasitism due to nematodes alone was 1.4% and 2.15% respectively. A few larvae parasitised by nematodes were also recorded on cotton in April and May, and on tomatoes in December.

4.1.4 1984-85 season general trends

The overall pattern of the different mortality factors on H. armigera larval population for the season is summarized in Figs. 25 and 26. Mortality built up rapidly from the beginning of the season and by December had reached its first peak. Although there was a small decline in January, larval mortality increased again up to the end of March before decreasing (Fig. 25). The early season mortality occurred between October and December when parasitism, in particular on larvae collected from Cleome was at peak. The level of parasitism declined rapidly after December, but this was followed by a sharp increase in the level of larval diseases (Fig. 25). The level of diseased larvae remained high between January and March, particularly in larvae collected on Cleome, maize, cotton, tomato and sorghum. After march, the level of diseases in the pest population declined.

The pattern of diseases and parasitism in relation to field populations on the different alternative hosts is shown in Figure 26. The pattern of larval parasitism and diseases on Cleome (Fig. 26a) was similar to the previous seasons. Larval parasitism was again prevalent in larvae collected from the weed between October and December, after which the level declined and remained low throughout the season (Fig. 26a). A late season build up of parasites was recorded in June, also reported in previous seasons. Although diseased larvae were available on the weed early in the season, diseases reached peak after December and persisted until mid June. As in previous seasons, peak larval mortality on Cleome was recorded in January and February (Fig. 26a).

Fig 25

Mortality of *H. armigera* larvae in the Ukiriguru vicinity 1984-85 season presented as total monthly percentages

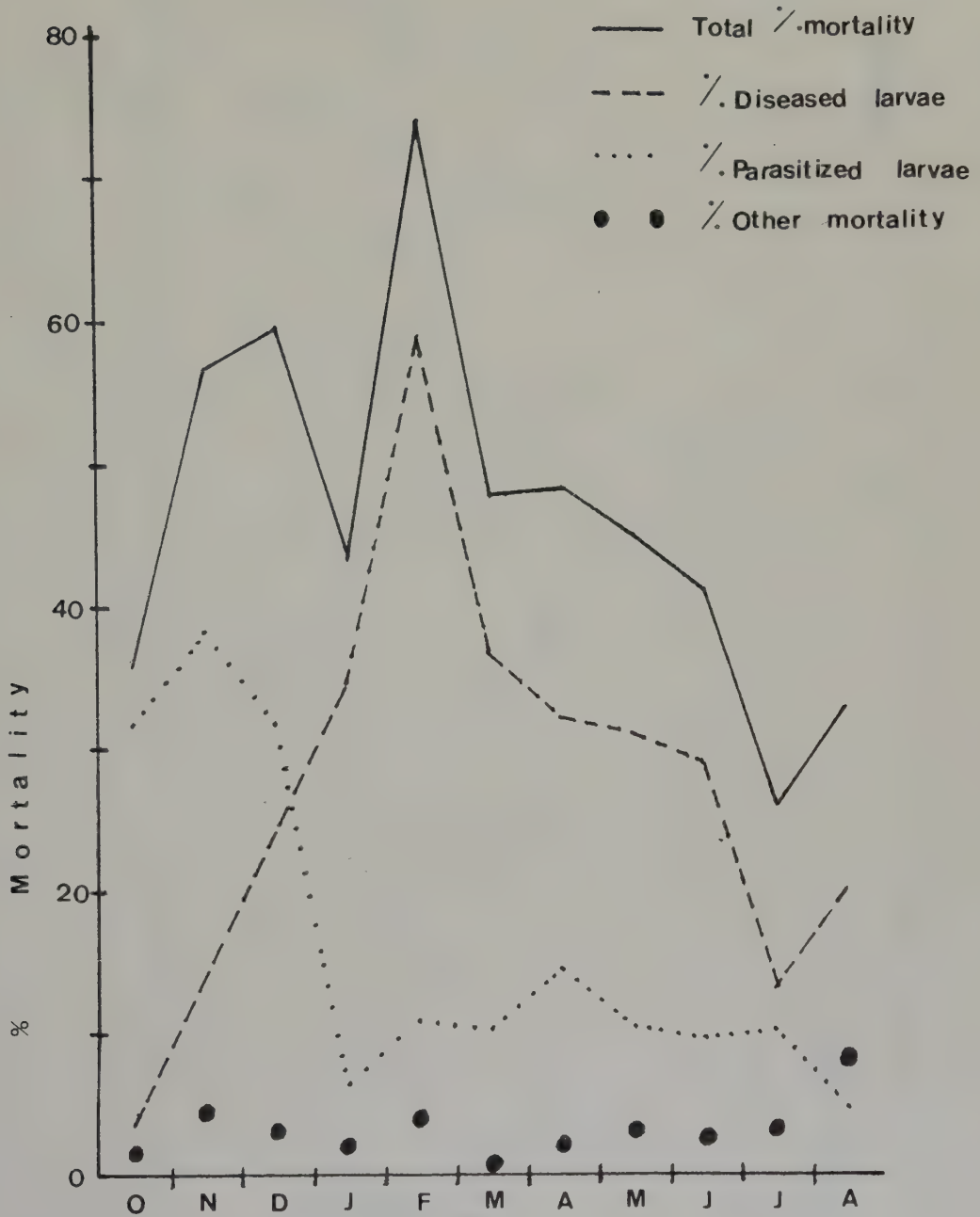


Fig 26 The relationship between the level of infestation and mortality factors (diseases & parasitism) on field collected *H. armigera* larvae in 1984-85 season presented as weekly means

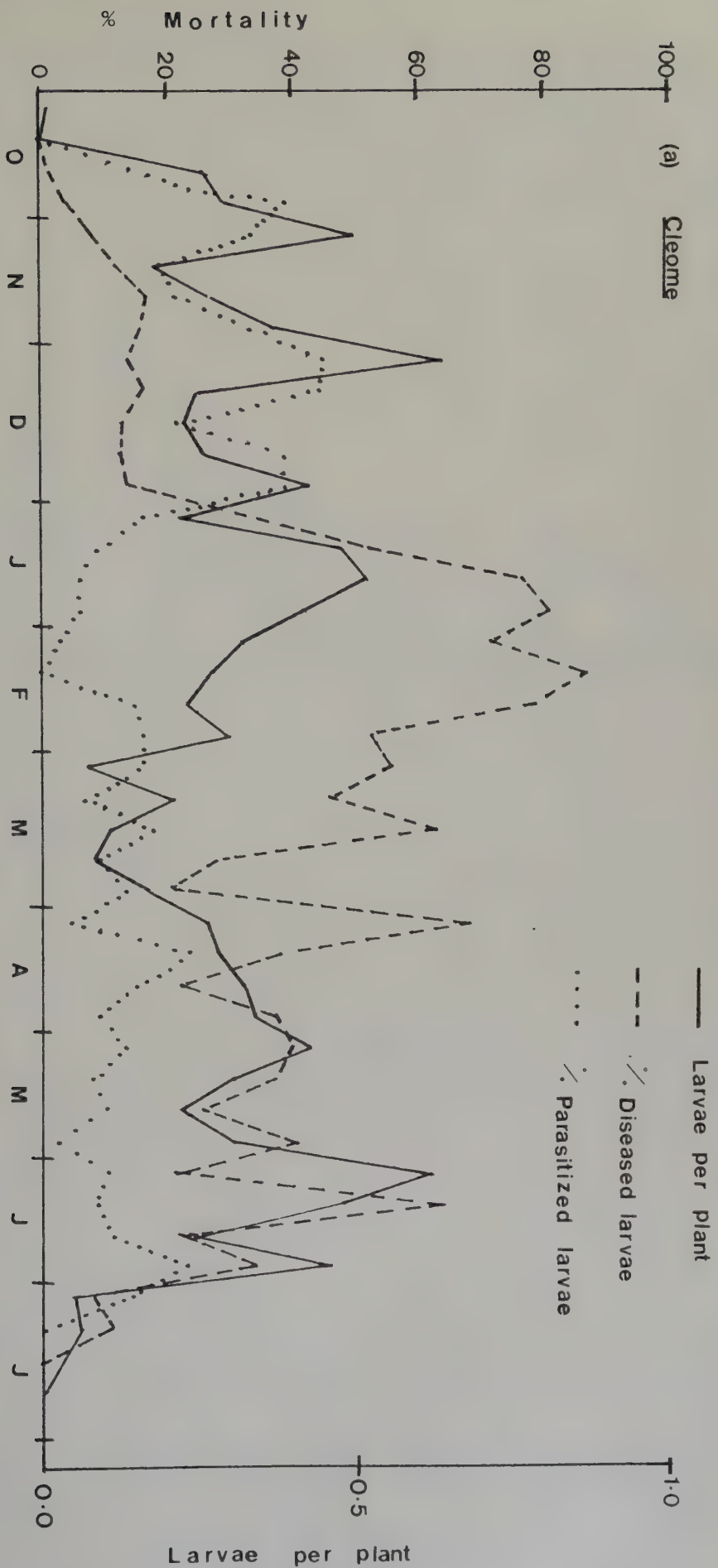


Figure 26 continued

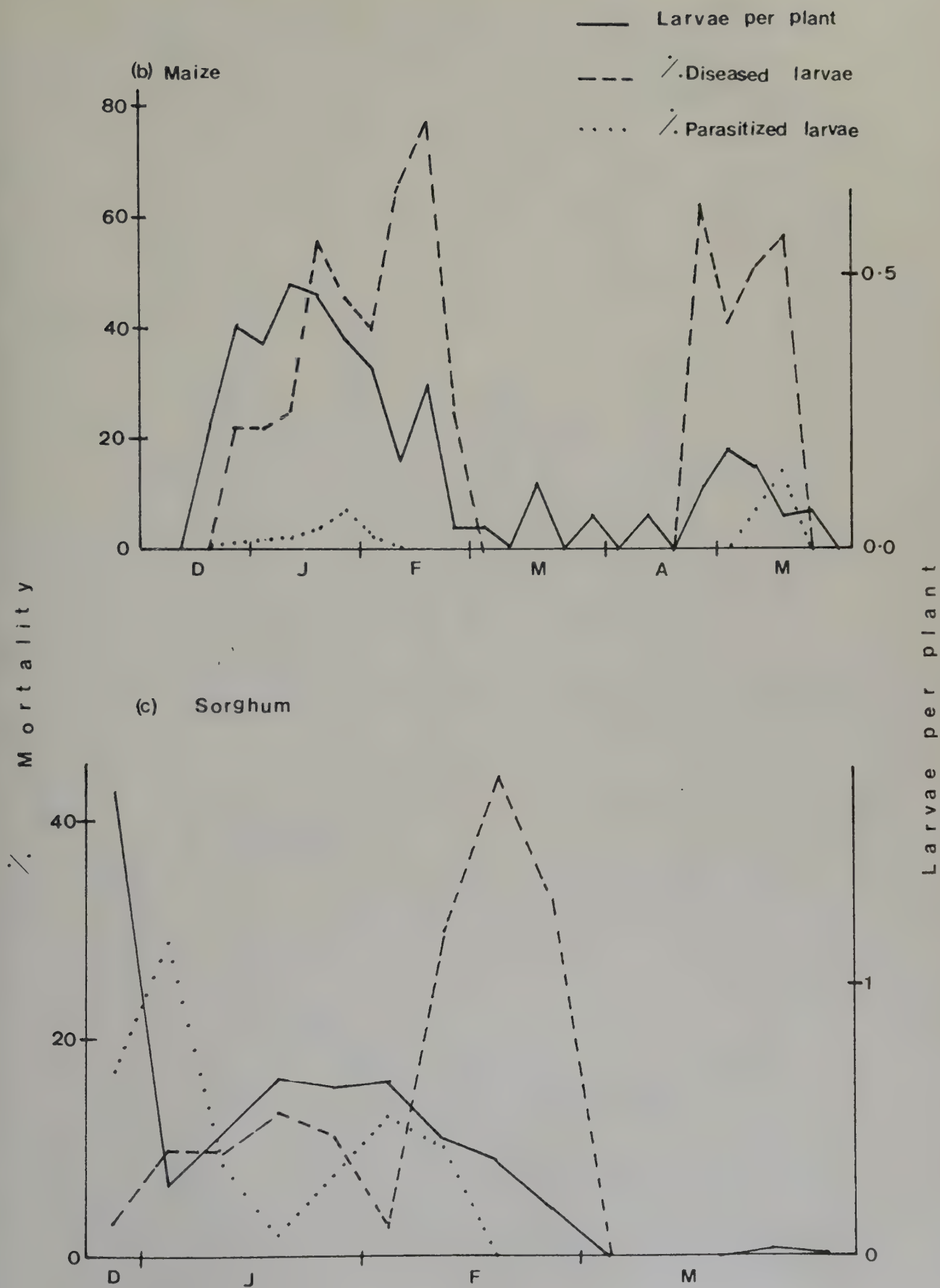


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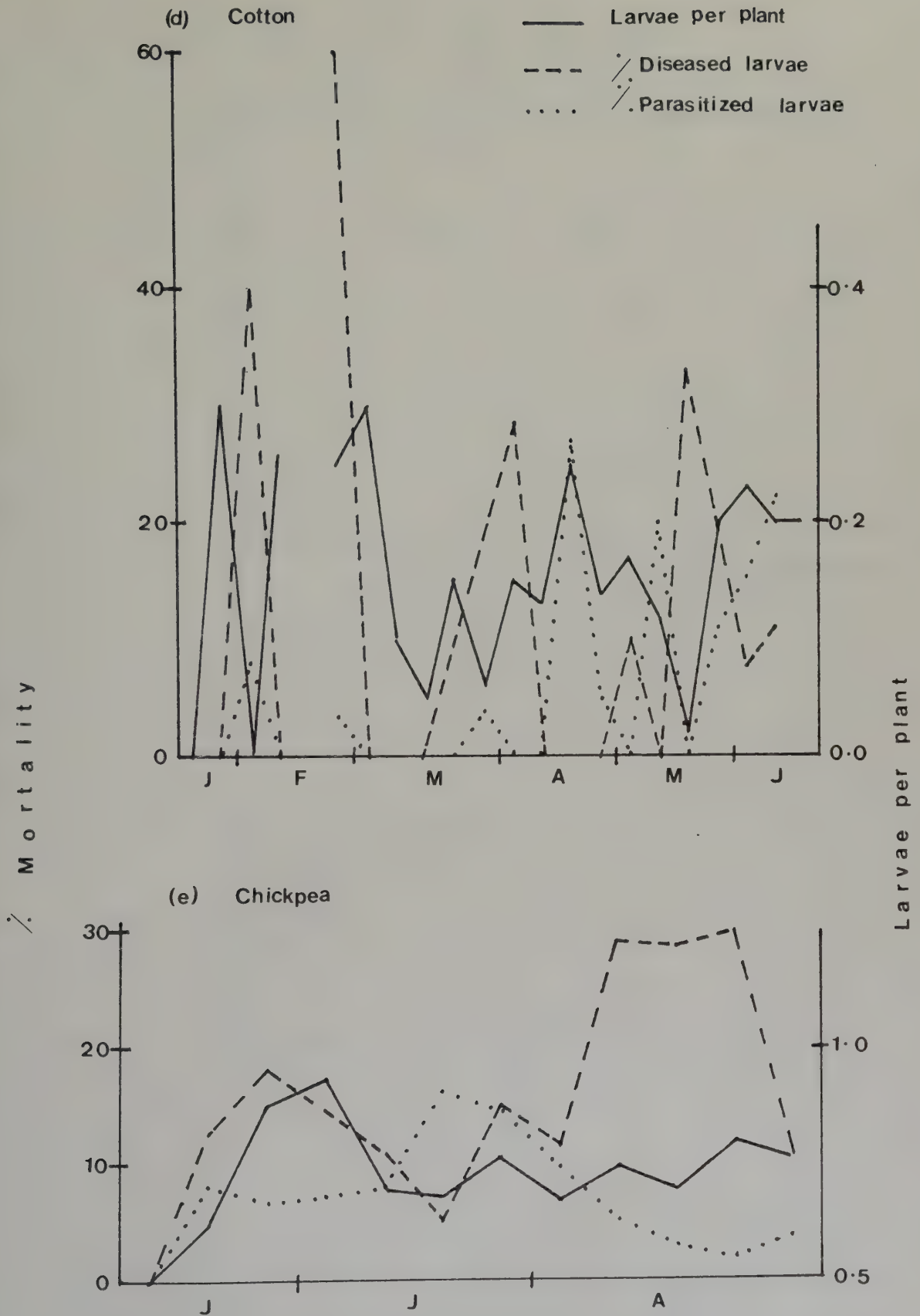
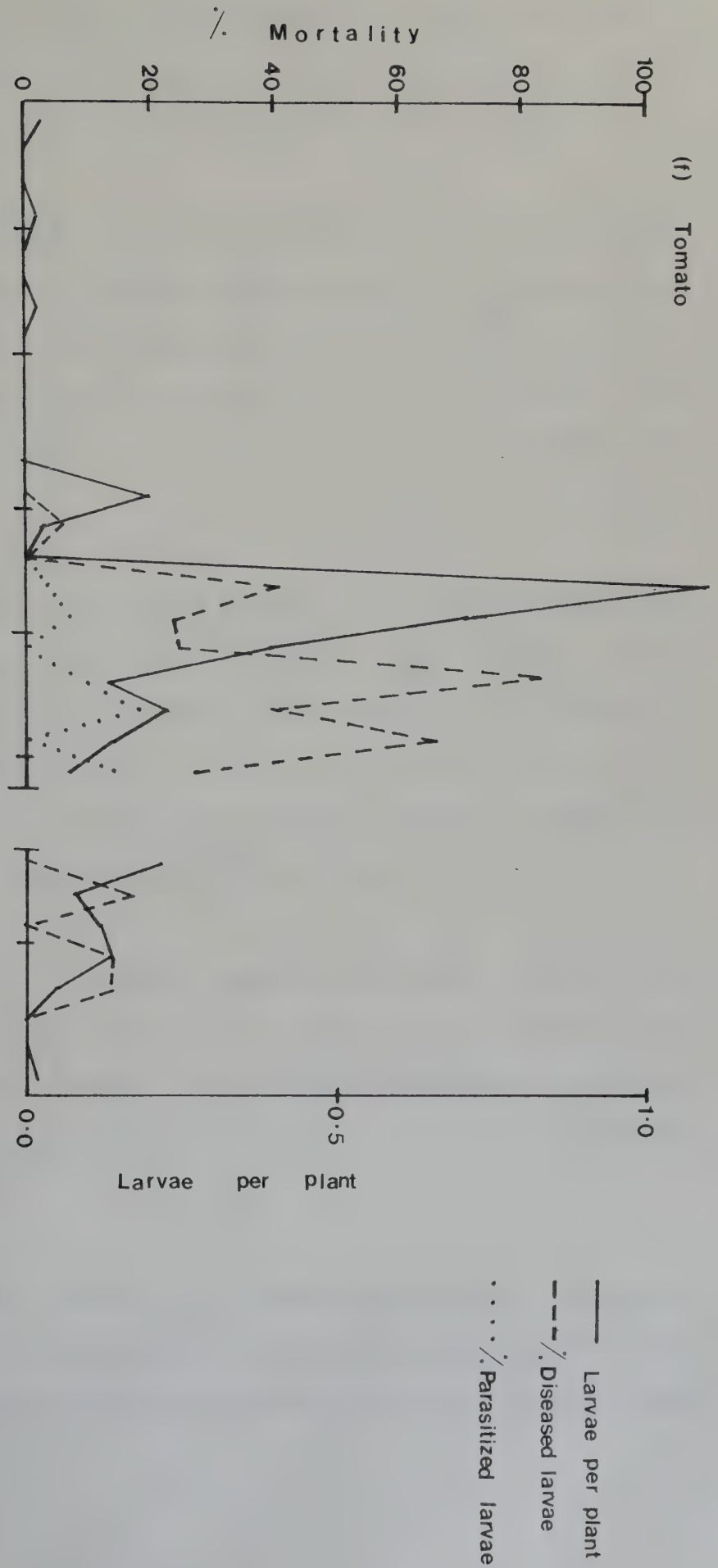


Figure 26 continued



On maize, Fig. 26b, larval diseases were again more prevalent than those parasitized throughout the season. Overall, the level of larval parasitism on maize was low compared with other hosts.

The sorghum season was short and by the end of March no sorghum was available, unlike in previous seasons when the crop was available to the end of May. Thus, the pattern of larval mortality (Fig. 26c) showed that larval parasitism was important for a short period in the first half of January, after which larval diseases became more prevalent.

On cotton, (Fig. 26d) larval diseases were much more common than parasitism although both mortality factors began to occur early in the season. Parasitism remained low up to mid April, but even at its peak, larval parasitism did not exert marked effect upon the pest population. Diseased larvae were recorded throughout the season but did not generally show any relationship with pest numbers.

On chickpea, (Fig. 26e), diseased larvae were recorded more frequently than parasitized ones. The level of diseases was particularly high in August. The level of parasitism was heavier than in most seasons especially in mid season between end of July and early August.

Tomatoes were sampled for a longer period partly because the level of infestation from October to December was very low. After December the level of infestation and parasitism and diseases began

to build up. Overall, larval diseases were more frequent over parasitism (Fig. 26f).

4.1.4.1. Diseases - Viral and bacterial diseases were the main pathogens in the pest population during the season. Their relative abundance on larvae collected from the alternative host is summarized in Table 11 and Figure 27. Overall, bacterial diseases were more frequent in larvae collected from cotton, sorghum, chickpea and tomatoes whereas viral diseases, particularly NPV, was very common on larvae collected from Cleome and maize, an observation also reported in previous seasons. The level of NPV in larvae collected from Cleome was very high from January to March, a time when peak larval mortality occurred. On maize, the level of NPV was high in January when diseases were more prevalent.

4.1.4.2 Parasitism - H. armigera larval parasites were recorded almost throughout the year except in September. Many of the parasites recorded in previous seasons were also active but their abundance (Appendix 4) and pattern of activity (Table 6) varied. Twelve genera comprising 14 species were recorded from the different alternative hosts. Cleome was associated with 13 species, tomatoes, maize and cotton 7, sorghum 6 and chickpea 3. As in previous seasons, there was high diversity between host plants except for a few of the species which were recorded only on Cleome (Table 12). Several species, including Charops sp. Netelia sp. and the tachinids, were recorded on all the alternative hosts of the pest. Last season, only Charops sp. and Cardiochiles spp. were recorded on all five alternative hosts of H. armigera.

Table 11. Mean monthly summary of the proportion of larvae of H. armigera with viral and/or bacterial infection during 1984-85 season.

Cleome

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Oct	40.0	60.0	5
Nov	38.4	61.6	86
Dec	45.1	54.8	62
Jan	80.6	19.4	268
Feb	65.3	34.7	170
Mar	63.6	36.4	66
Apr	23.1	76.9	78
May	47.8	52.2	113
June	71.6	28.3	134
July	0.0	0.0	0
Aug	0.0	0.0	0
Sept	0.0	0.0	0

Maize

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Dec	59.2	40.7	54
Jan	52.1	47.8	303
Feb	63.6	36.3	22
Mar	33.3	66.6	3
Apr	45.4	54.5	11
May	59.4	40.5	37

Sorghum

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Dec	20.0	80.0	35
Jan	45.8	54.1	24
Feb	0.0	100.0	4

Table 11 (Continued)

Cotton

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Jan	21.7	78.2	23
Feb	31.6	68.4	19
Mar	25.0	75.0	16
Apr	33.3	66.6	3
May	0.0	100.0	8

Chickpea

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Jun	12.2	87.8	41
Jul	21.6	78.4	102
Aug	39.5	60.5	119

Tomato

Month	% Virus	% Bacteria	Total Number of Diseased larvae
Jan	30.2	69.7	76
Feb	48.1	51.8	27
Jun	20.0	80.0	5
Jul	100.0	0.0	1

Fig 27 Mean monthly % mortality due to virus and bacteria on *H. armigera* field collected larvae and observed in the insectary during 1984-85 season

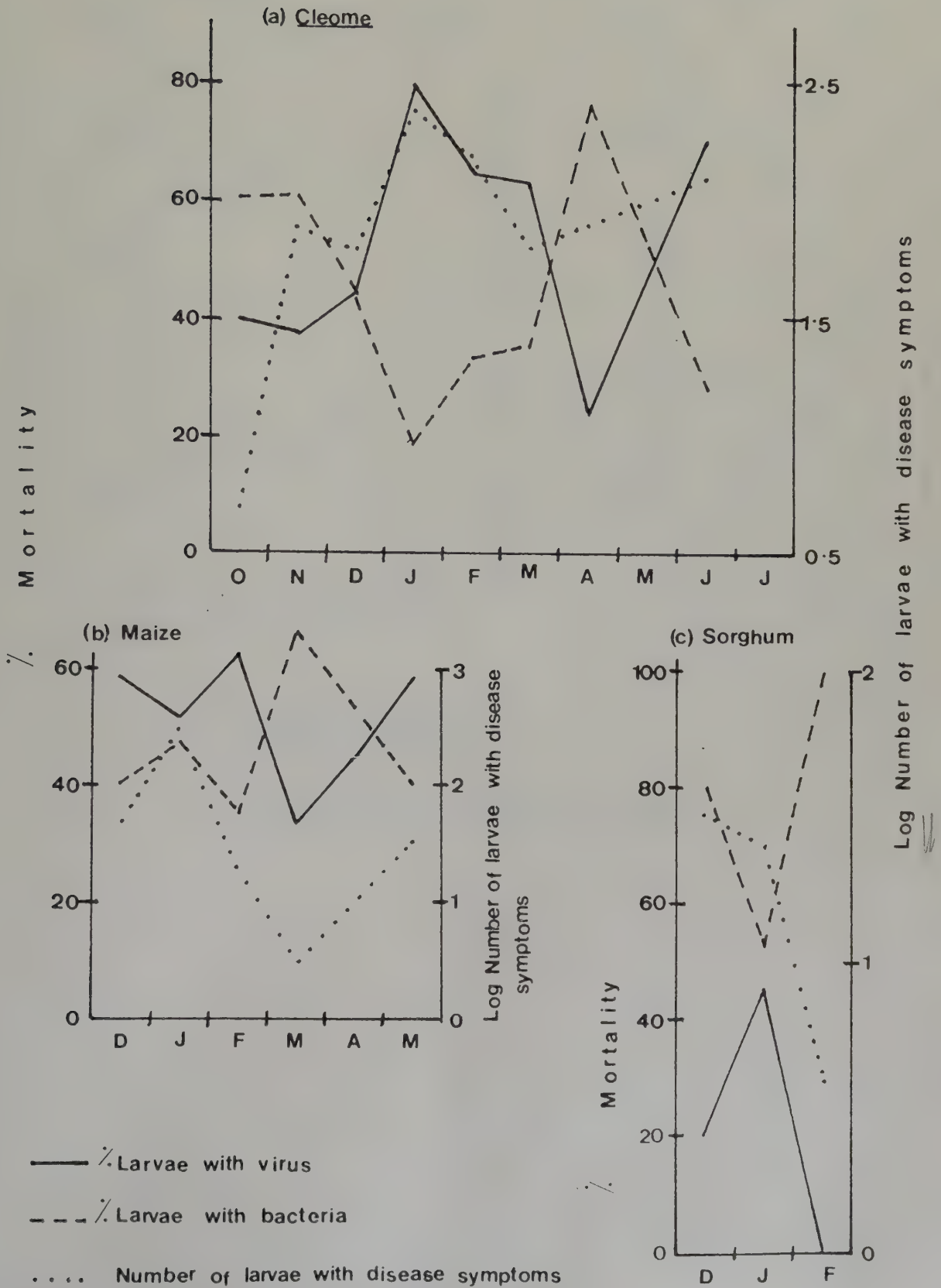


Figure 27 continued

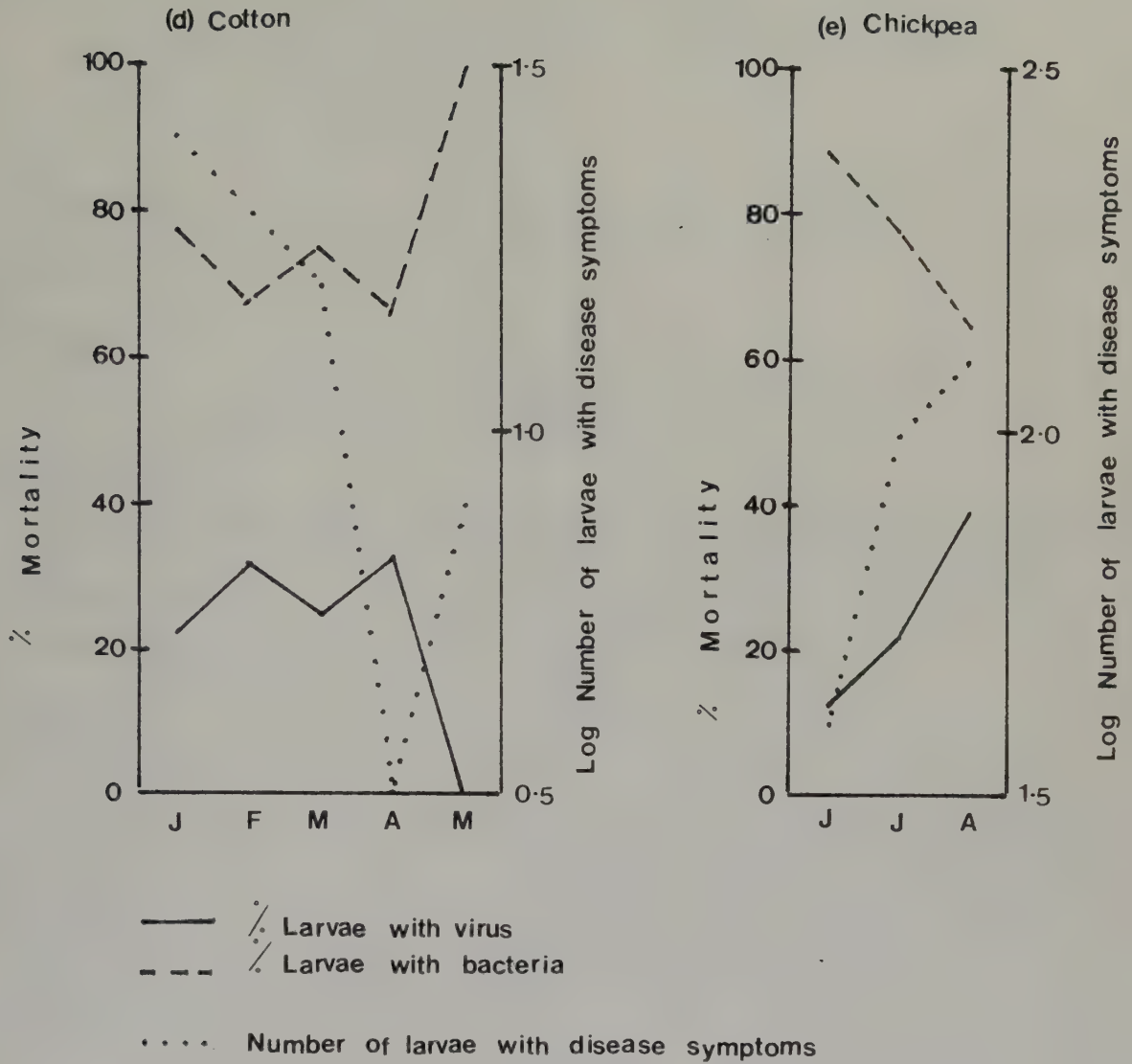


Table 12. The relative abundance of different species of adult parasites emerging from H. armigera larvae on different hosts during the 1984-85 season.

Parasite	Host Plant
HYMENOPTERA	
Braconidae	
- <u>C. sp</u> (nr. <u>C. trimaculata</u>)	<u>Cleome</u> ¹ , Cotton ² , Tomato ³
- <u>Cardiochiles</u> sp	
- <u>C. (Microchelonus) curvimaculatus</u>	Maize ¹ , Sorghum ² , Cotton ³ , Tomato ⁴
- <u>A. diparopsidis</u>	Sorghum ¹ , <u>Cleome</u> ² , Maize ³ , Tomato ⁴
- <u>A. sp</u> (<u>vitripennis</u> sp. group)	<u>Cleome</u> ¹ , Maize ²
- <u>Meteorus</u> sp.	<u>Cleome</u>
Ichneumonidae	
- <u>Charops</u> sp	Chickpea ¹ , <u>Cleome</u> ² , Tomato ³ , Sorghum ³ , Cotton ⁴
- <u>Netelia</u> sp	<u>Cleome</u> ¹ , Maize ² , Sorghum ² , Cotton ³ , Tomato ⁴
- <u>Pristomerus</u> sp	<u>Cleome</u> ¹ , Maize ² , Cotton ²
Other hymenoptera	
- A	<u>Cleome</u>
- C	<u>Cleome</u>
- E	<u>Cleome</u>
DIPTERA	
Tachinidae	
- <u>P. halli</u>	Chickpea ¹ , Cotton ² , <u>Cleome</u> ³ , Sorghum ⁴ , Maize ⁵ , Tomato ⁵
- <u>P. laxa</u>	Sorghum ¹ , Chickpea ² , Cotton ³ , Maize ⁴ , <u>Cleome</u> ⁴ , Tomato ⁵

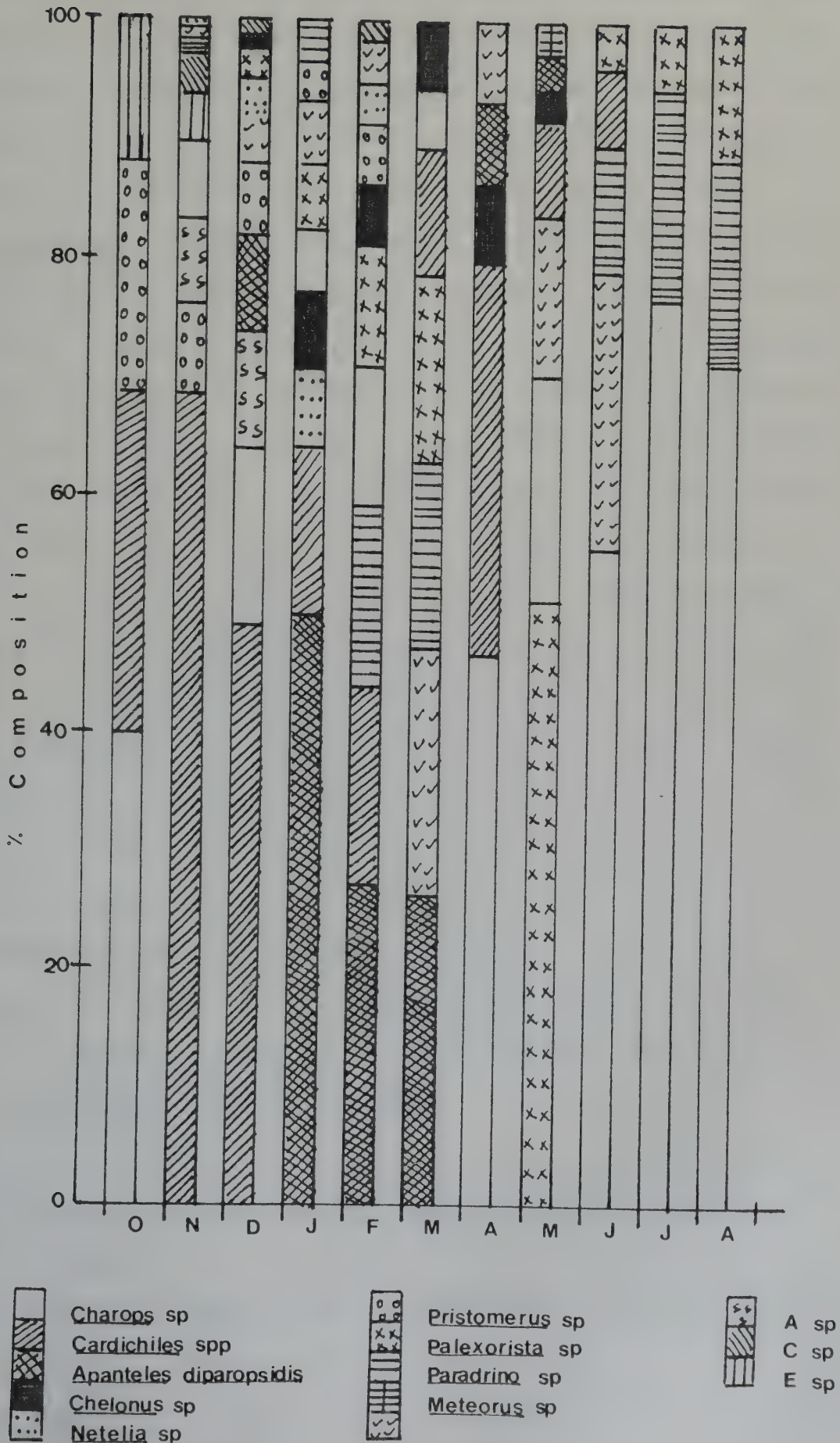
1 = Most abundant

5 = least abundant

Despite, or perhaps because of a wide host plant diversity, few of the parasites could be considered important on any particular host plant. Thus, on Cleome, Cardiochiles spp., Charops sp., A. sp. (vitripennis sp. group), Pristomerus sp., A. diparopsidis (Lyle) and species 'A' were recorded in relatively high numbers. A. diparopsidis (Lyle) was the only parasite recorded in high numbers on maize. On sorghum, A. diparopsidis (Lyle) and P. laxa (Curran) were the common ones although their level of activity was lower compared to 1981-82 season. On cotton, P. laxa (Curran) and P. halli (Curran) were the only common parasites whereas on chickpea, Charops sp. and P. halli (Curran) were the most active. No parasite was common enough to be considered important in tomato, as in 1981-82 and 1982-83 seasons.

The number of species active at a particular time of the year varied throughout the season (Fig. 28). However, as in previous seasons, several species could be active at any one time of the year. In addition, the number of species active tended to increase from October to May, after which fewer species were recorded up to the end of the season.

A few of the species were present throughout the year, and there were certain months when they were most common (Table 6, 1984-85 season). Charops sp. was recorded from October to August with peak activity in June, July and August especially on larvae collected in chickpea. Cardiochiles spp. were recorded from October to June, with a peak in November - December on larvae collected on Cleome. A.



diparopsidis (Lyle) was active from December to May, with peak activity in January - February on larvae collected on sorghum, maize and Cleome; whereas A. sp. (vitripennis sp. group) was active from November to June with a peak in June, a contrast with the previous season when the species was active over a shorter period. C. (Microchelonus) curvimaculatus (Cameron) was recorded from December to May reaching peak in January - February, mostly on larvae collected on maize. Last season the species was recorded on Cleome alone. Netelia sp. was recorded on a wide range of host plants but it occurred in such low numbers that it could not be considered important on any of the host plants, an observation also made in previous seasons. Pristomerus sp. was active from October to February, with large numbers being recorded on larvae collected on Cleome in October to December. A similar observation was made last season. P. laxa (Curran) was recorded from November to August with a peak in May, mostly on larvae collected on sorghum, whereas P. halli (Curran) was active from January to March; and from June to August with peak numbers being recorded in the latter part of the year on larvae collected in chickpea. Species 'A' was recorded only in November and December on Cleome whereas 'C' was very common in November on Cleome. Species 'E' was recorded for the first time on larvae collected on Cleome in October and November only. Only one specimen of Meteorus sp. was recorded.

4.1.5 Summary and discussion of four seasons work, 1981-82 to 1984-85

4.1.5.1 General trends - There were considerable seasonal variation

Fig 29 Mean percentage level of parasitism and diseases of H. armigera larvae for the period 1981-82 to 1984-85 for each individual host.

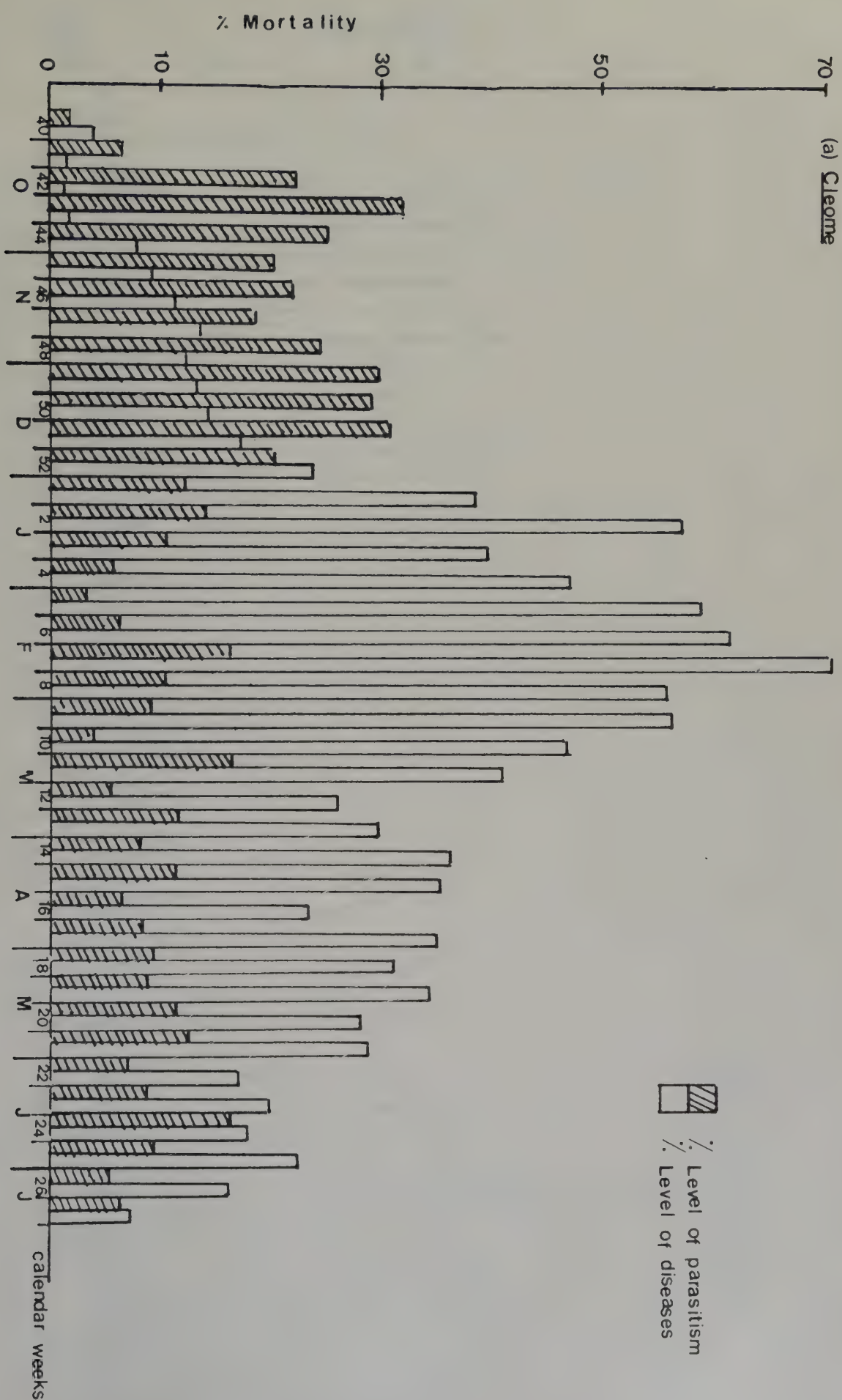


Figure 29 continued

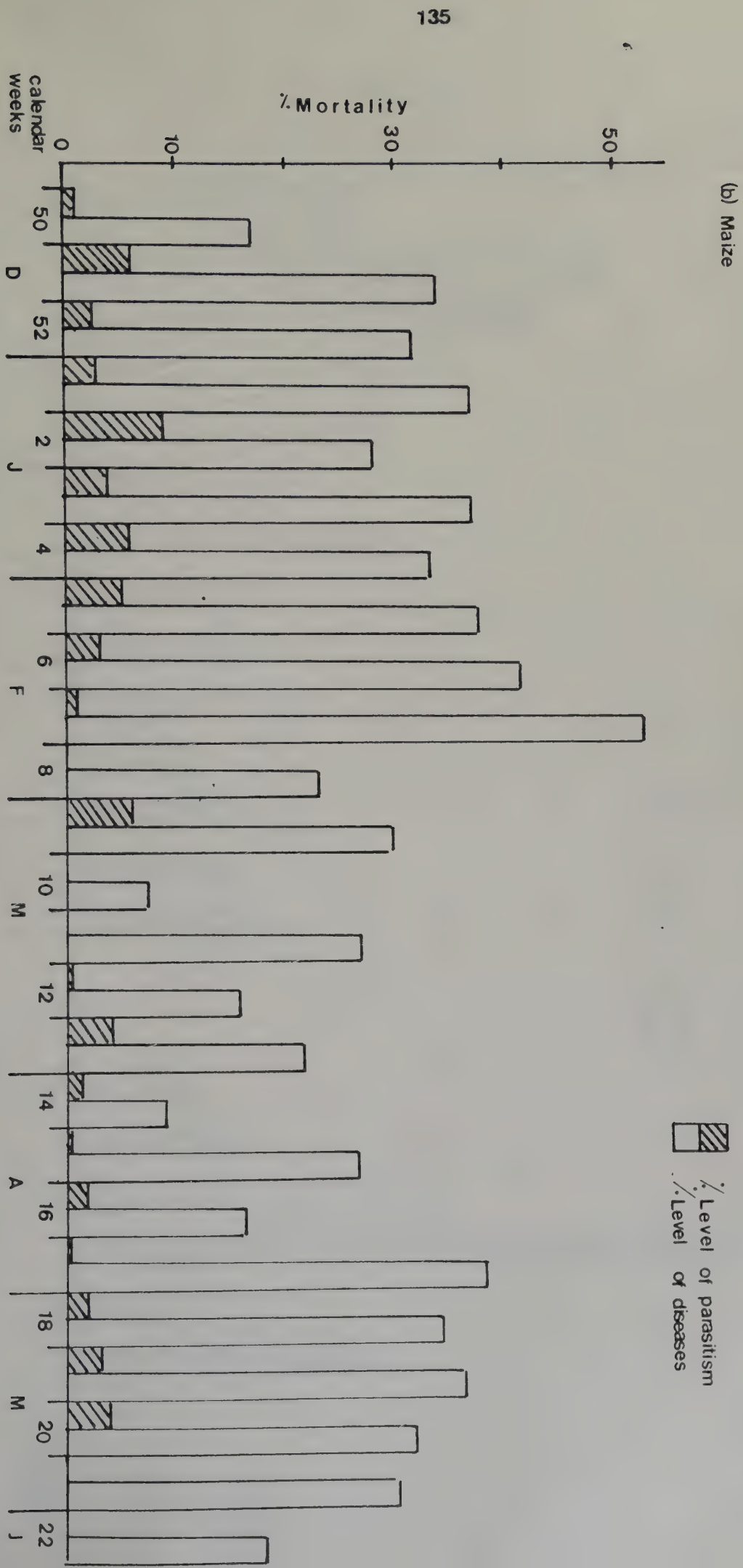


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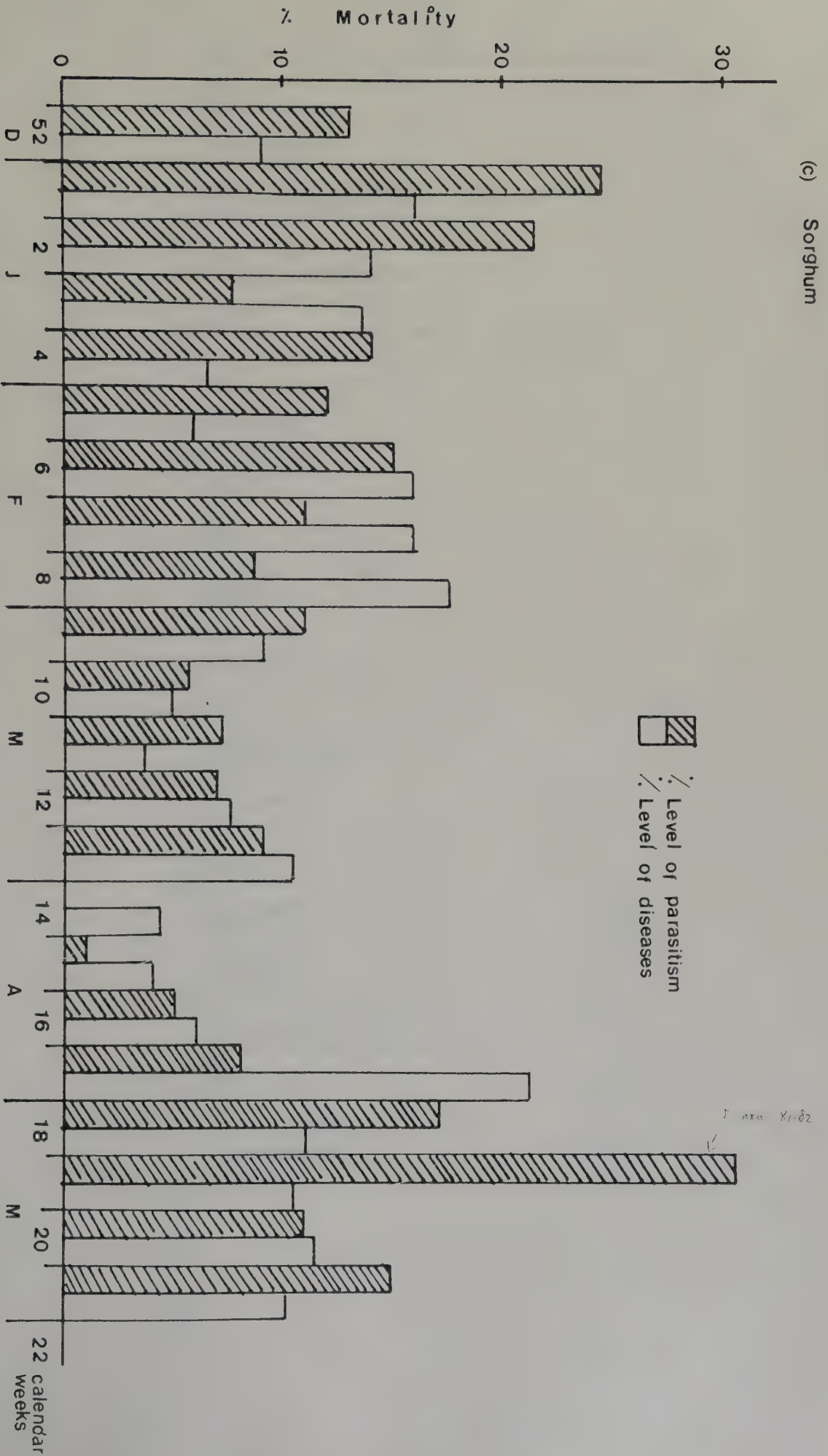


Figure 29 continued

(d) Cotton

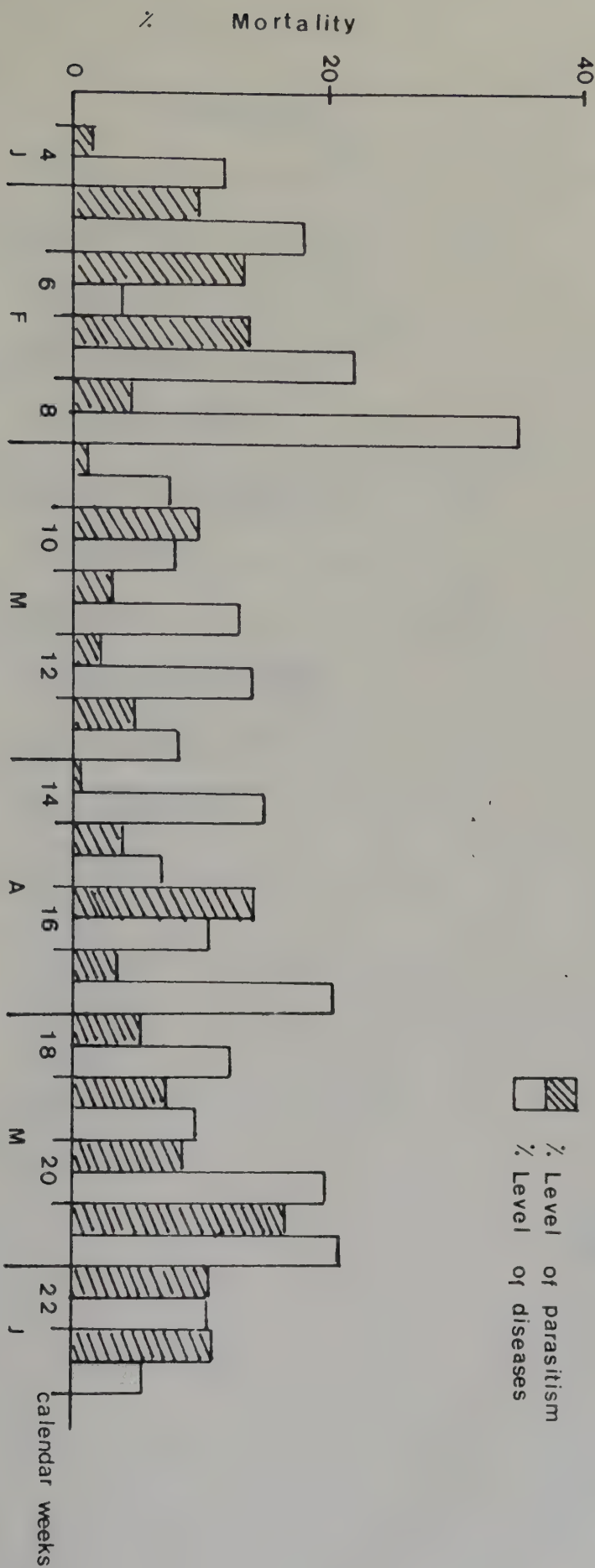


Figure 29 continued

(e) Chickpea

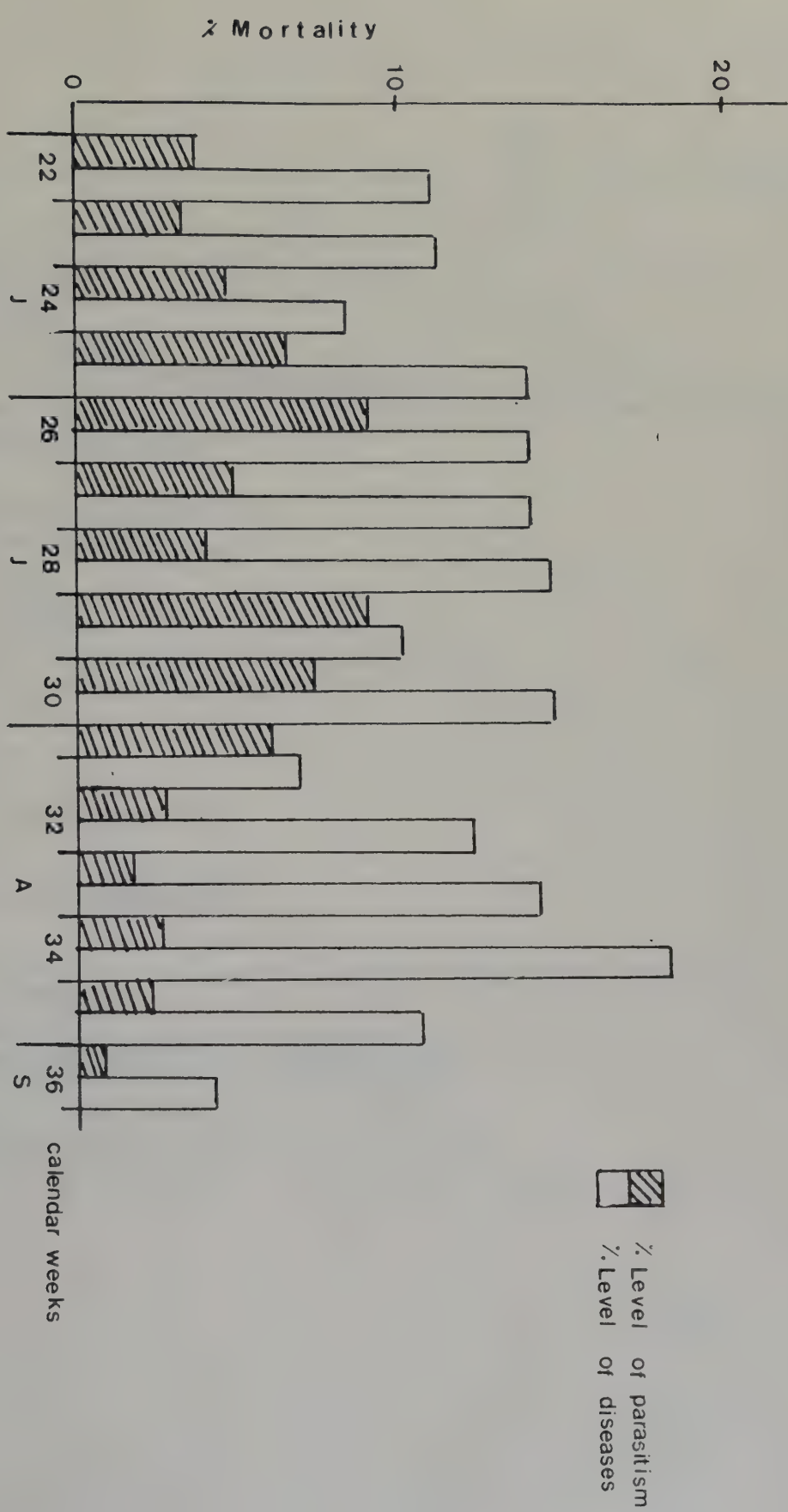
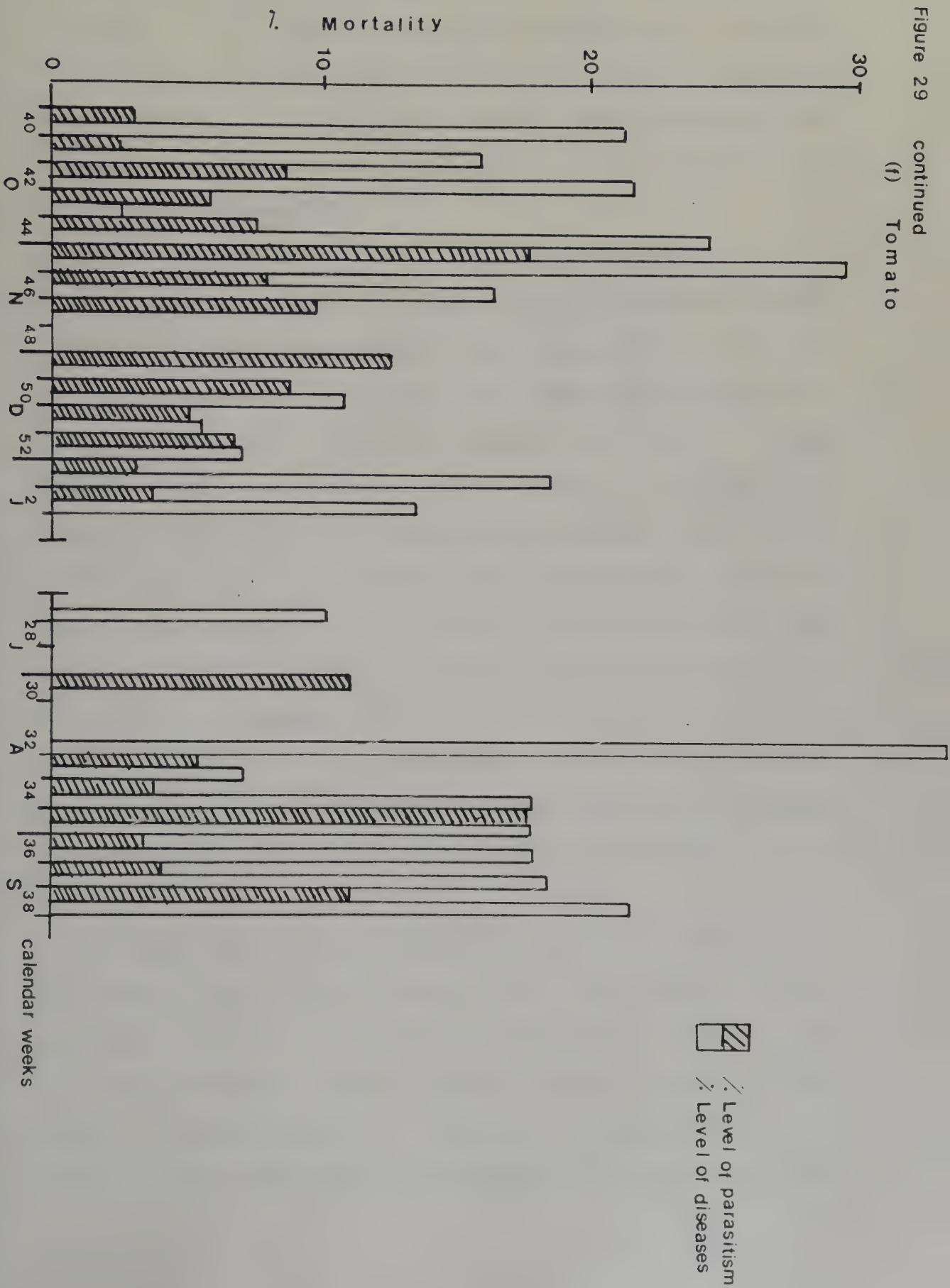


Figure 29 continued
(f) Tomato



in the sizes of the pest populations largely associated with differences in the seasonal amounts and distributions of rainfall which seemingly influenced the level and activity of H. armigera larval mortality factors. The overall pattern and level of parasitism and diseases of larval populations is summarized in Figures 29a-f and Appendix 5.

On Cleome parasitism and diseases began to increase from the beginning of the season in October (Fig. 29a and Appendix 5a). The level of parasitism built up rapidly to a peak in October, when the population of larvae killed by parasites was 31.7%. Larval parasitism was a more common mortality factor on Cleome up to December, after which the level declined and persisted at low numbers to the end of the year. A further small peak occurred towards the end of the season but at a time when the pest population was declining (Fig. 12). Diseases did not occur frequently early in the season until early January when there was a rapid increase to a peak in February, when larval mortality reached a peak of 70% (Fig. 29a). After February the level of diseases decreased gradually but remained an important larval mortality factor to the end of the season.

On maize, larval diseases were more important than parasitism in most seasons (Fig. 29b and Appendix 5b). The level of larval parasitism was generally very low, with an average of 9% at peak parasitism in January, whereas diseases caused an average of 53% mortality at peak infection. The pattern of larval diseases was bimodal, a direct reflection of the activity of the pathogens on the

main generations originating on the main maize crops; the short maturity crop early in the season and the long maturity crop late in the season (Fig. 12). Throughout the study, larval diseases on the crop was observed to be density dependent and this may explain the pattern of disease build up.

The pattern of larval mortality factors on sorghum shows that overall, larval parasitism was a more prevalent mortality factor than diseases particularly in early January when parasitism reached 24.5% at the peak (Fig. 29c and Appendix 5c). As on maize, the level of both larval parasitism and diseases showed a bimodal pattern. The high level of parasitism early in the season occurred on the early crop of sorghum between the end of December and February; whereas late in the season parasites built up on the pest population on ratoon and late season crops (Fig. 12). The level of diseases, often less than 20% followed a similar pattern.

On cotton, larval diseases were more common than larval parasitism (Fig. 29d and Appendix 5d). Both mortality factors began to build up on the pest population early in the season but although the level of parasitism reached a peak in February when mortality reached 13%, the level was comparatively low. After the peak in February the level of larval parasitism declined up to mid April when it increased to 16.6%, possibly too late in the season to be of economic importance. Similarly, the level of larval diseases remained generally low especially between March and April. The level of disease at this time of the season averaged 15% but increased to

20% towards the end of the season. The number of diseased larvae at the beginning of the season was also high, about 41%, but the pest population level at the beginning of the season was generally low (Fig. 12).

On chickpea, larval diseases were a more prevalent mortality factor than larval parasitism although both factors were generally recorded at low levels. At peak larval mortality, diseases caused an average of 21% mortality whereas parasites caused only 8% mortality (Fig. 29e and Appendix 5e). The number of larvae killed by pathogens increased rapidly from the beginning to the end of the season. In contrast, the level of larval parasitism did not show dramatic changes but rather remained persistently low (Fig. 29e).

Tomatoes were not monitored for H. armigera population changes throughout the seasons, and therefore the comments that follow would apply only to the time of the year when the crop was consistently monitored over the four seasons (Fig. 12). Considering the period October to December, larval diseases were more prevalent than parasitism except in December when the level of larval parasitism built up gradually to a peak in November, with a record of 17%, but at a time when the pest population was at its lowest (Figs. 12 and 29f and Appendix 5f). In contrast, the level of larval diseases at the beginning of the season was higher. During the dry season, both larval parasitism and diseases were generally lower compared to the October-December period, and although the mean larval parasitism ranged between 10 to 33.3% in August - September, the pest population

size in the dry season was often very low (Fig. 12).

4.1.5.2. Diseases - During October - December tomatoes and Cleome are the only two important hosts for the pest (Fig. 12) and therefore the only sources of diseased larvae. However, more diseased larvae occurred on tomatoes than on Cleome (Fig. 30a). As the season progressed, the number of available suitable alternative host plants increases (Fig. 12) and larval pathogens probably disperse within and between the different hosts as the pest population increase. Most diseased larvae were recorded on Cleome followed by maize, cotton, sorghum and chickpea (Fig. 30b). Throughout the study, NPV was recorded more frequently on larvae collected from Cleome and maize plants than on any of the other hosts whereas bacterial infected larvae were more commonly recorded on larvae collected from cotton, tomatoes, chickpea and sorghum.

Overall, more diseased larvae occurred on the Cleome than on chickpea plants (Fig. 30c). In August and September, more diseased larvae were recorded on chickpea than on tomatoes. Chickpea is a low growing plant compared with tomatoes and may therefore offer a more suitable microenvironment for pathogens to build up on the larval population.

Although little is known about the natural distribution of H. armigera larval pathogens on alternative host plants of the pest, Callahan (1962) and Reed (1965b) reported a higher incidence of NPV disease on larvae collected from and subsequently fed on maize than

Fig 30 Comparison of the mean seasonal level of H. armigera larval diseases on its alternative host plants for the period 1981-82 to 1984-85

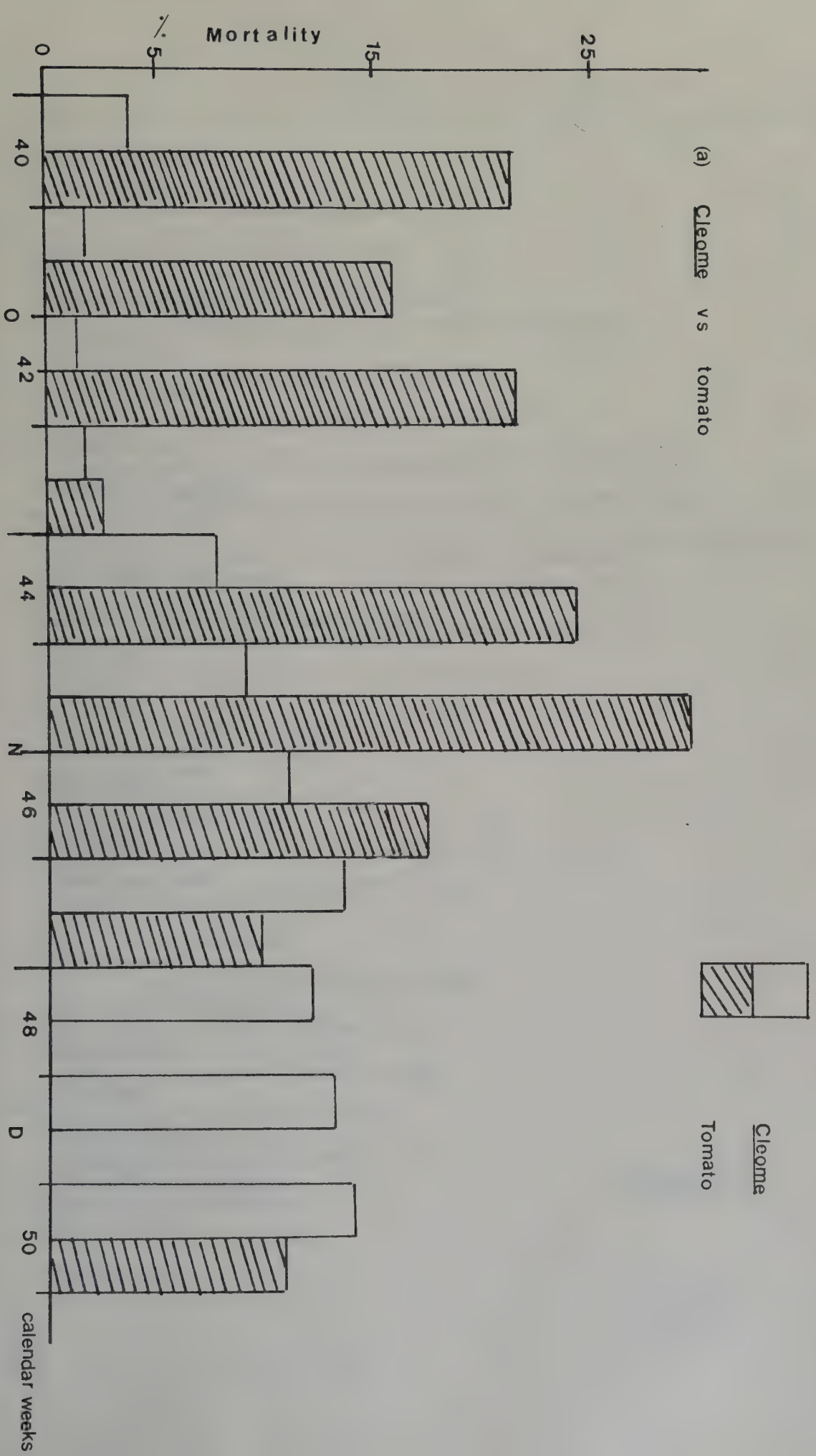


Figure 30 continued

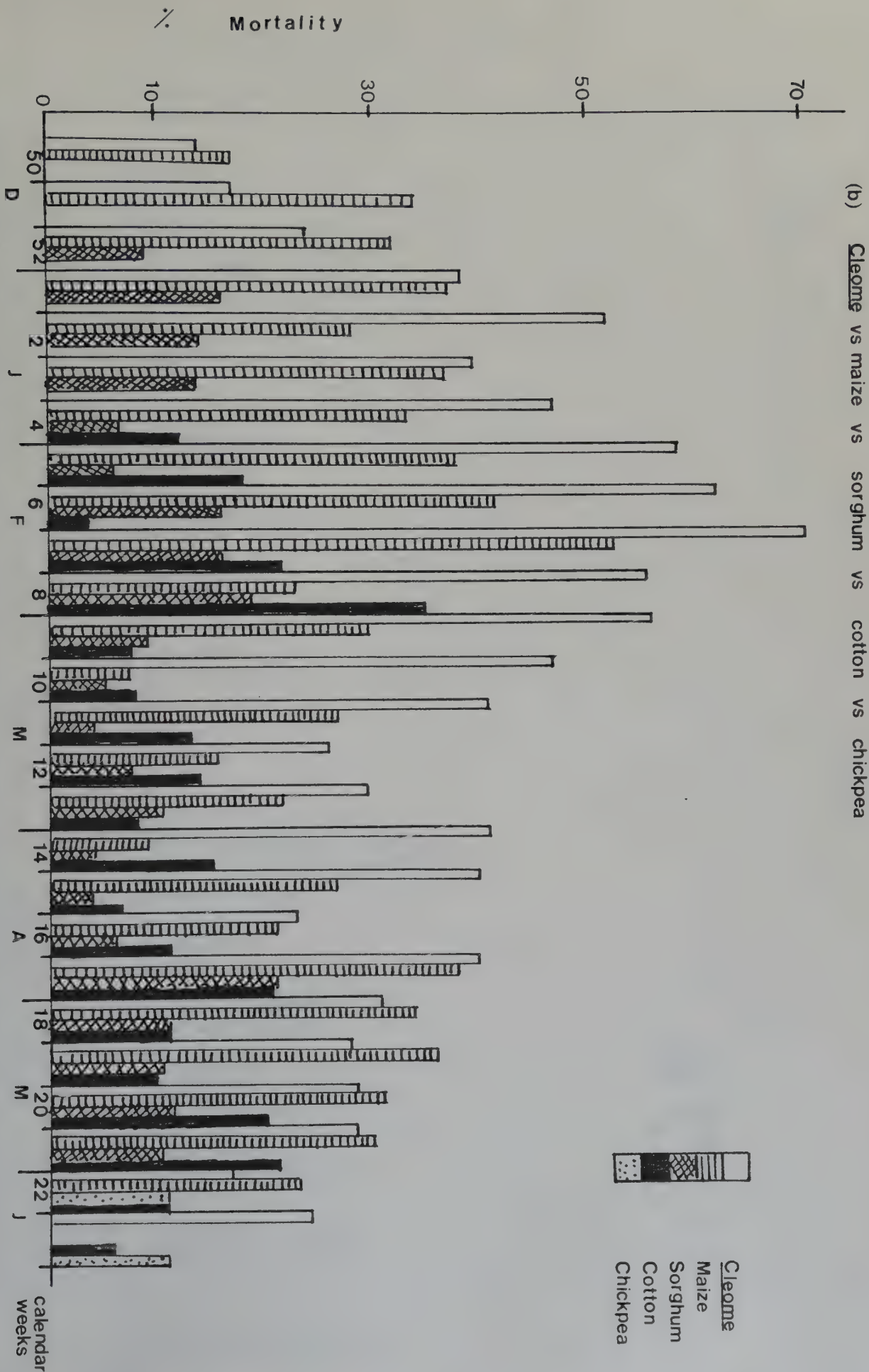
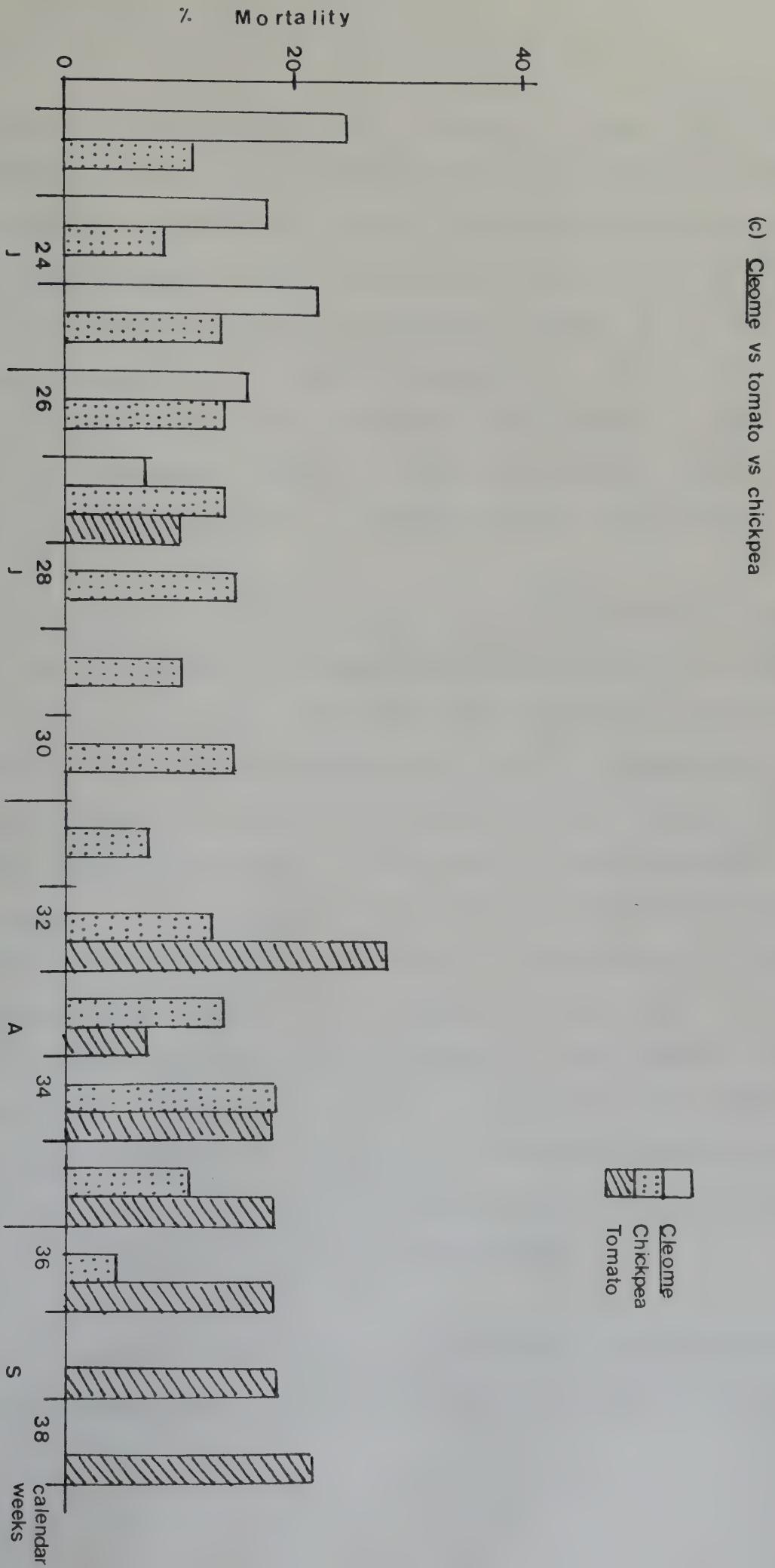


Figure 30 continued



on cotton. Also, Beeden (1976) observed a higher level of polyhedrosis virus on larvae collected from tobacco than from cotton and tomatoes. Evidence from a closely related pest species H. zea, which feeds on maize in the USA, shows that the virus is sometimes spread by ovipositing adults from silk to silk (Oatman, et al; 1970), a fact which may help to explain the apparent high level of NPV on larvae collected from maize. Furthermore, the attractive stage of maize to ovipositing adults is relatively long and therefore increases the possibility of dispersing NPV pathogen than on sorghum.

Differences in the nature of the leaf and the feeding sites of different hosts could also influence the level of polyhedrosis virus in the pest population. Thus, the surface environment of cotton leaves has been shown to inactivate the NPV of H. armigera in the presence of sunlight (Yearian and Young, 1974; Maïorov, et al 1984; Elleman and Entwistle; 1985). This may partly explain the overall low incidence of polyhedrosis virus in larvae collected from cotton plants. Also, the 'hidden' and solitary feeding behaviour of H. armigera larvae, particularly on cotton and tomatoes could account for low levels of viral diseases observed on larvae collected from these plants. In contrast, the larval population on sorghum plants may be particularly dense, but the level of diseased larvae remained very low. This is in contrast with other hosts where high larval densities were associated with high disease levels.

4.1.5.3. Parasitism - The level of parasitism and abundance of the larval parasites varied, seasonally and with host plants (Appendix 4

Fig 31 Comparison of the mean seasonal level of H. armigera larval parasitism on its alternative host plants for the period 1981-82 to 1984-85

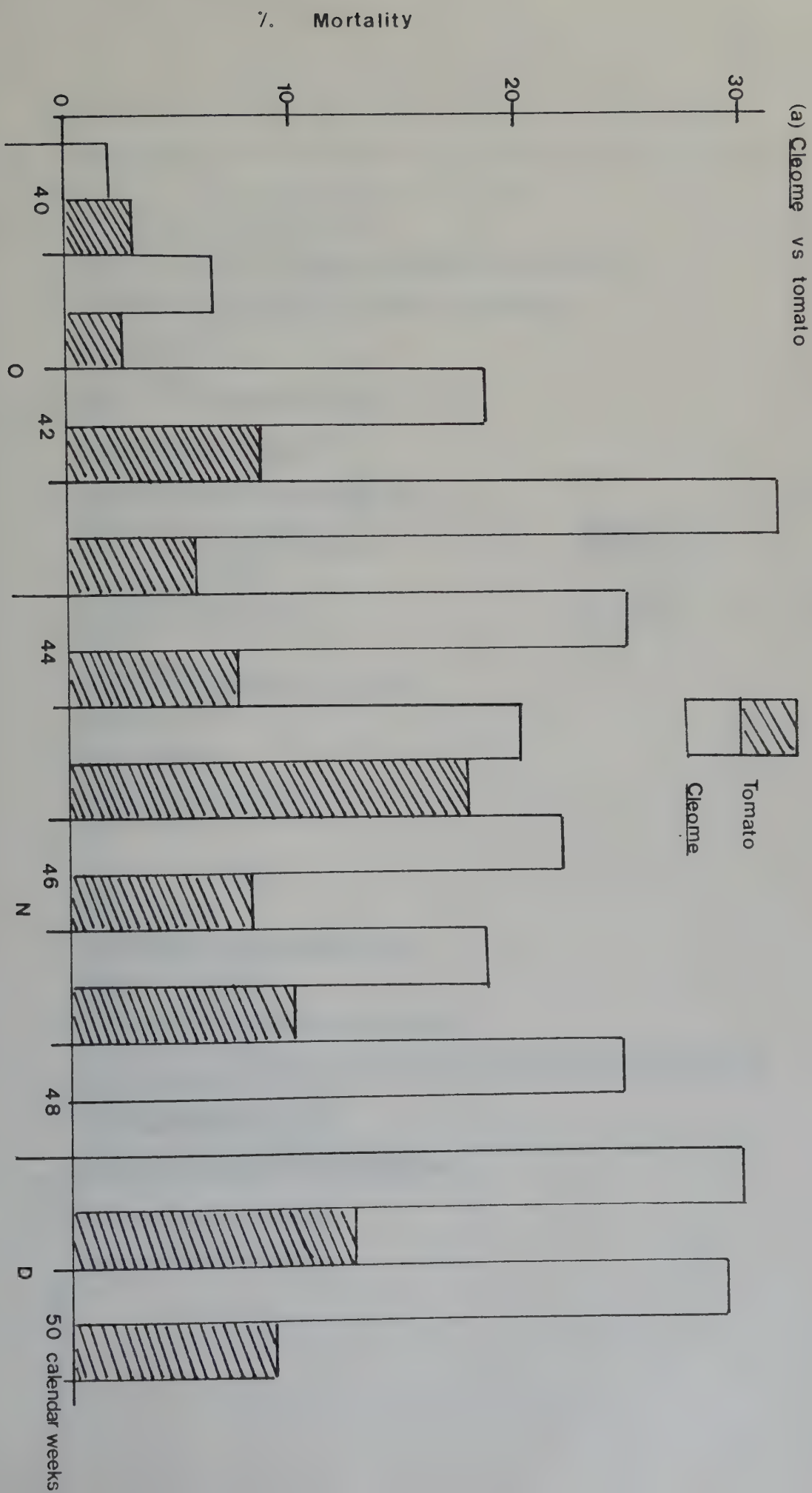


Figure 31 continued

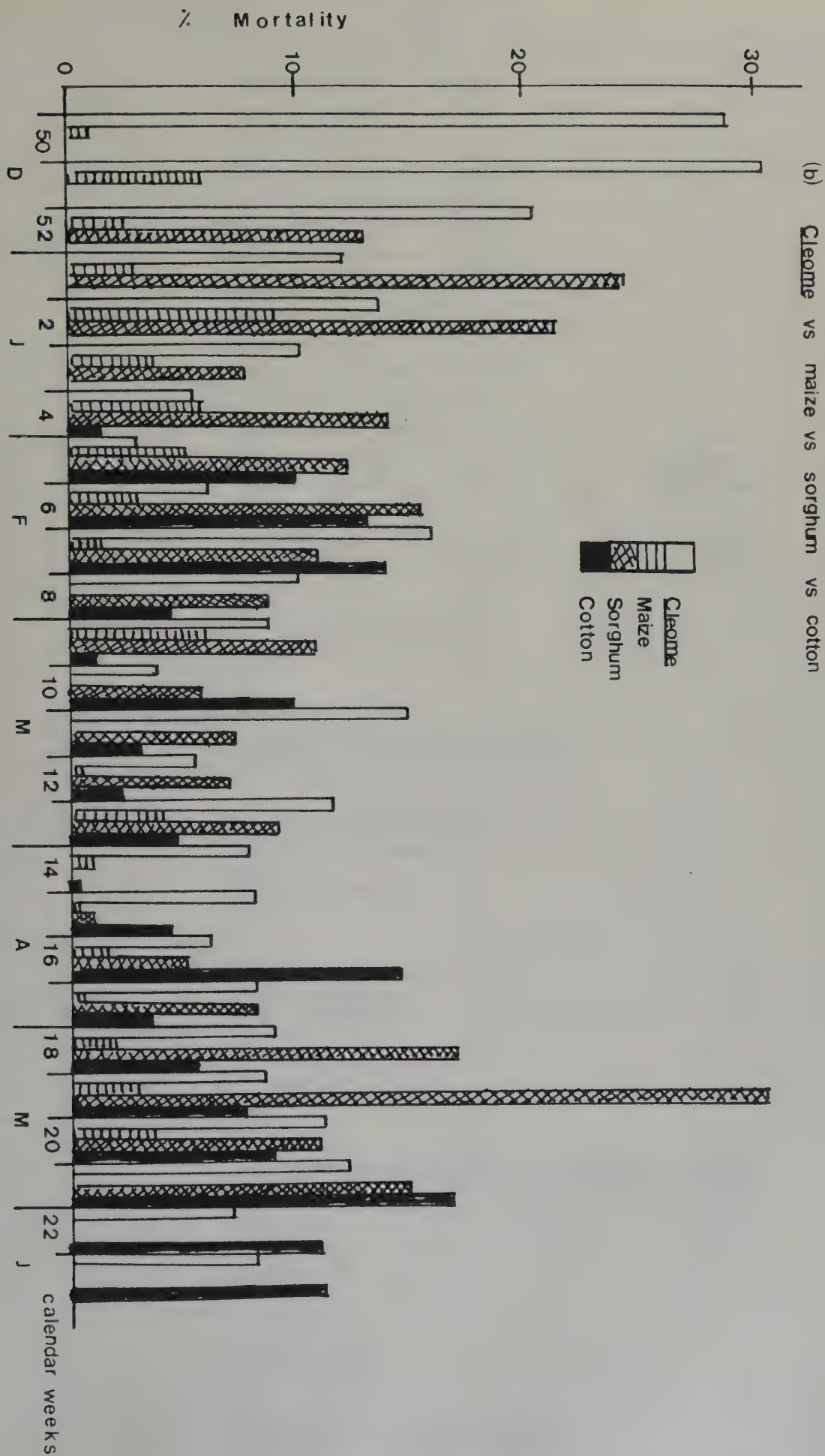


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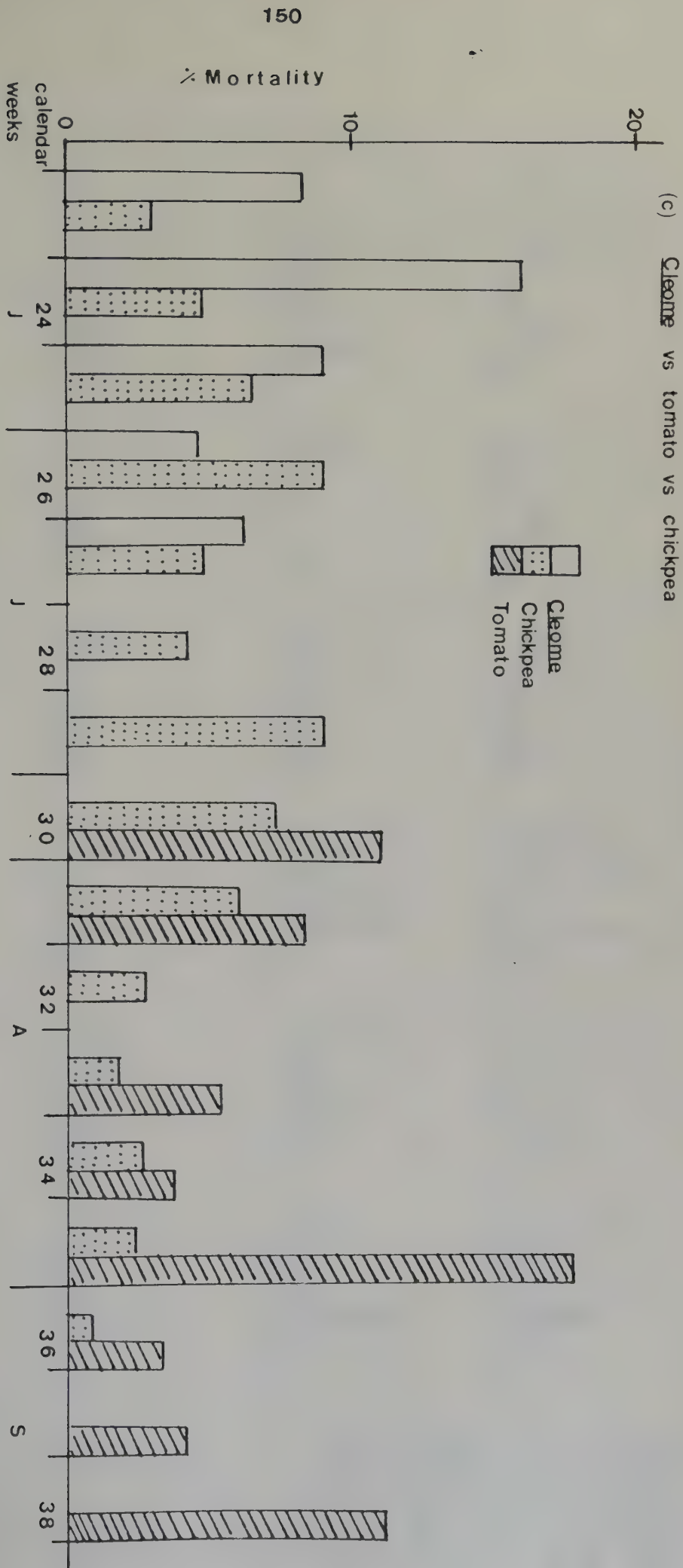


Fig 32 Comparison of seasonal total number of adult parasite species emerging from H. armigera larvae from different host plants 1981-82 to 1984-85.

Log Total number of adult parasite species +1

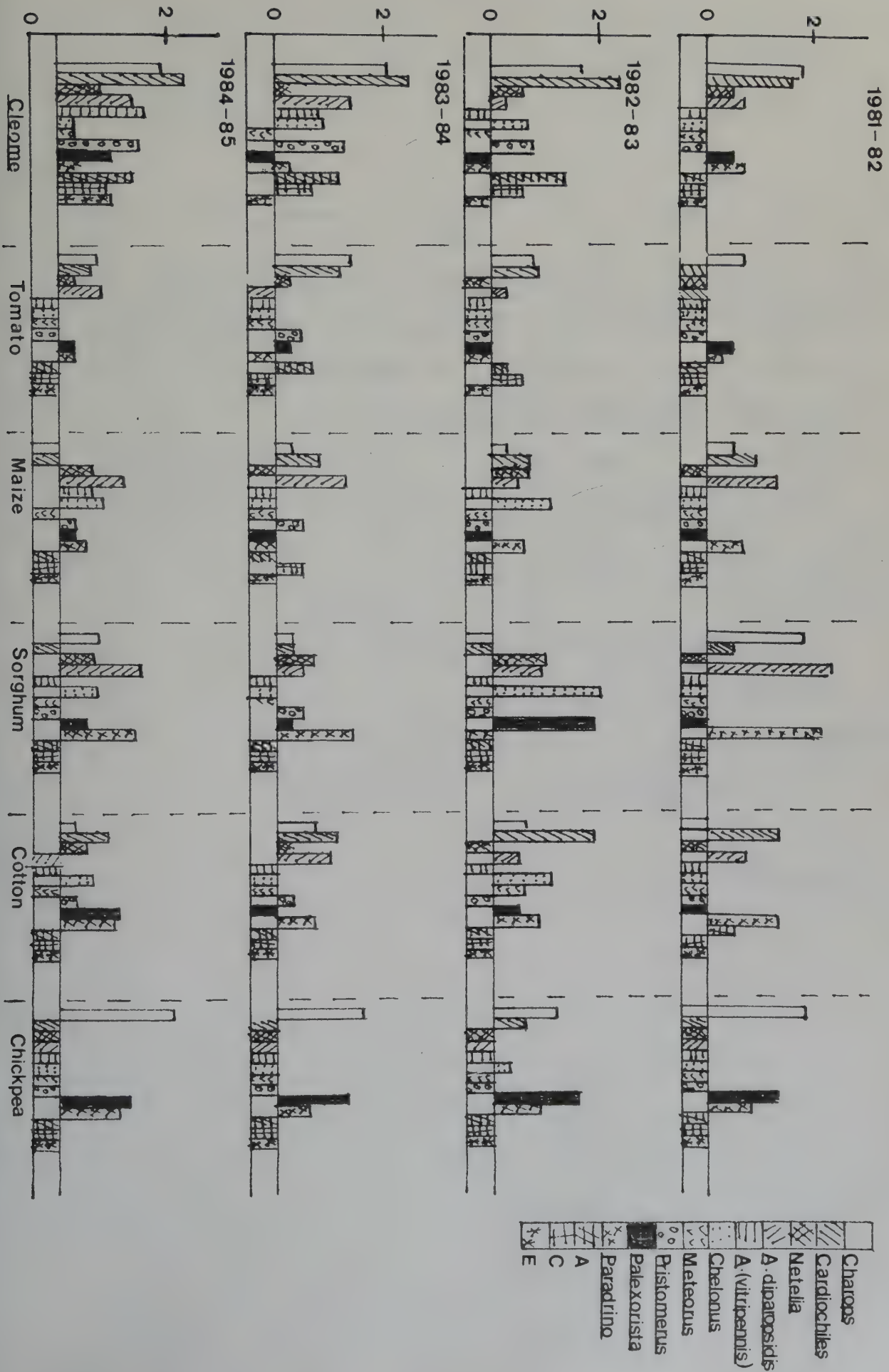


Table 13 Overall relative abundance of the parasite adults emerging from H. armigera larvae on the different hosts from 1981-82 to 1984-85

Rank	Season			
	1981-82 (Dry)	1982-83 (Wet)	1983-84 (Dry)	1984-85 (Wet)
1	<u>A. diparopsidis</u>	<u>Cardiochiles</u> spp.	<u>Cardiochiles</u> spp	<u>Cardiochiles</u> spp
2	<u>Charops</u> sp	<u>Charops</u> sp	<u>Charops</u> sp	<u>Charops</u> sp
3	<u>P. laxa</u>	<u>C. (microchelonus)</u> sp.	<u>A. diparopsidis</u>	<u>Apanteles diparopsidis</u>
4	<u>Cardiochiles</u> spp	<u>P. laxa</u>	<u>P. laxa</u>	<u>P. laxa</u>
5	<u>Netelia</u> sp	<u>P. halli</u>	<u>Pristomerus</u> sp	<u>P. halli</u>
6	'A'	'A'	<u>P. halli</u>	<u>A. sp (vitripennis sp group)</u>
7		<u>Netelia</u> sp	'A'	<u>Pristomerus</u> sp.
8		<u>A. diparopsidis</u>	<u>C. (microchelonus)</u> sp	'A'
9		'C'	<u>Netelia</u> sp	<u>Netelia</u>
10		<u>Pristomerus</u> sp	'C'	<u>C. (Microchelonus)</u> sp.
11		<u>Meteorus</u> sp	<u>A. sp (vitripennis sp group)</u>	'E'
12				'C'
13				<u>Meteorus</u> sp.

& 5; Figs. 31 & 32; Table 13). Thus, early in the season, October - December, Cleome and tomatoes are the only hosts available in quantity but the percentage parasitised larvae was higher on Cleome possibly because the pest population was generally higher on the weed (Figs. 12 and 31a). During the main cropping season, December to May, Fig. 31b, parasitised larvae were more commonly recorded on sorghum than on Cleome, cotton and maize particularly between December and February. Between March and April, a higher number of parasitised larvae were recorded on Cleome than on sorghum, cotton and maize. In May, the level of parasitised larvae was higher on sorghum than Cleome, cotton and maize. In June, cotton and Cleome were the main sources of parasitised larvae but the level of parasitism was usually higher on Cleome. Towards the end of June the pest population levels on chickpea increased rapidly but the level of larval parasitism remained low in the crop compared to the weed (Fig. 31c). In August, when both tomatoes and chickpea are the cultivated alternative hosts of the pest population, the level of larval parasitism was higher on tomatoes, but percent parasitism on tomatoes was derived from a very small larval population.

There is evidence from the study that the level of parasitism was related to host plant factors. Larval parasitism was generally higher on sorghum than on cotton, chickpea, tomatoes and maize. In the absence of sorghum, Cleome had a higher level of parasitised larvae than the other hosts. Similar findings have been reported elsewhere and in different host plants - pest situations (Walker, 1940; Parsons, 1940a; Rabb and Bradley, 1968; Roome, 1971; Young and

Price, 1975; Vinson, 1976; Bhatnagar and Davies, 1976; 1977; 1978; Bhatnagar, 1980; Bilapate, 1981; Dean, Jones and Powell, 1981; Pair, Laster and Martin, 1982). A number of factors seem to be involved. There is strong evidence that the host-habitat acceptability may play an important role in the behaviour of many parasitoids which may or may not parasitise a preferred host larvae depending on which plant species it infests (Walker, 1940; Rabb and Bradley, 1968; Vinson, 1976; Pair, 1982; Inayatullah, 1983). The plant often provides the first cue in the chain of events that leads to the host location. Plant defense mechanism, for example the sticky exudates on chickpea plant surface and hairiness on cotton leaves may directly decrease the efficiency of a parasitoid. At Ukiriguru, only the large parasitoids, mostly tachinids and ichneumonids, were commonly recorded from larvae collected in chickpea plants. Bhatnagar (1980) noted a low H. armigera parasitism on eggs on chickpea and pigeon pea and that parasite adults were trapped by the sticky exudation on the plant surface on chickpea plants. Similar plant defence mechanism has been reported to affect the efficiency and level of parasitism of Trichogramma minutum on tobacco leaves (Rabb and Bradley, 1968). The commercial cotton varieties grown in Tanzania are hairy as a defense mechanism against jassid damage, but could also be a deterrent to parasitoids as these may impede parasite efficiency (Pearson, 1958). Even when a host is successfully parasitised, the parasite may fail to develop due to chemical defense mechanism found in the host plant. For example, on tomatoes, larvae of Hyposoter exigua in H. zea failed to develop because the parasite larvae are poisoned by α -tomatine present in the host haemolymph (Campbell and Duffey, 1979).

The feeding behaviour of H. armigera larvae on its alternative hosts are also important. On cotton, the larvae are often scattered over the plant and feed confined in buds, flowers and bolls thus making it difficult for searching parasitoids. In contrast, on sorghum the larvae feed exposed on the ears where they are exposed to natural enemies (Plate 2).

Therefore, despite an early season build up of a number of parasitic species on Cleome, sorghum and maize, the level of parasitism and species attacking H. armigera larvae on cotton may not necessarily be high. Thus, the differential attractiveness of different crops or cultivars to parasites as opposed to the pests themselves is little researched (Nyambo, 1984) but it is a pre-requisit for a successful augmentation or introduction of natural enemies for the control of the pest.

Throughout the study, larvae collected on maize were least parasitized. Other workers from the USA on the corn earworm (Oatman and Platner, 1970; Graham, Hernandez and Llanes, 1972) and on H. armigera in Northern Nigera (Beeden, 1976) and in Australia (Kay, 1980) had similar findings. However, Parsons (1940a) in South Africa, Coaker (1959) in Uganda and Rens (1977) in Kenya reported higher incidences of larval parasitism in H. armigera on maize than on cotton. Local differences in the composition of the parasitic species involved may account for these differences.

The abundance and level of parasitism varied between the seasons

(Table 13 and Fig. 32). Seasonal variations has also been reported by other workers (Parsons, 1940a; Robertson, 1973; Dean, Jones and Powell, 1981) but there is little information on the factors involved. Parsons (1940a) suggested that climate was an important factor in determining the seasonal activity of Trichogramma sp. on rain grown crops of cotton and maize. Rainfall, relative humidity, wind and temperature are climatic factors which could have significant influence on the abundance and level of activity of parasites. There were obvious differences in the level of parasitism between 1983-84, a dry season, and 1984-85, a rainy season (Appendix 5). However, the overall abundance of the parasites recorded from H. armigera larvae (Table 13) cannot be solely explained by rainfall. A. diparopsidis Lyle, for example, was recorded in very high numbers from larvae collected on sorghum in 1981-82 only (Appendix 4) although the species tends to be more active in drier seasons (Table 13). Similarly, Cardiochiles spp. were significantly less abundant in 1981-82 season but were very common in subsequent seasons. At Ukiriguru, the long term mean temperature variations are low (Fig. 4) and therefore may not have a significant influence on the overall activity of the parasitic species.

In 1983 the light trap catches at Ukiriguru were examined for the period January to May. These catches showed that two ichneumonids (I.D. Gauld det.) Enicospilus antefurcalis (Szépligeti) and E. sp? capensis (Thunberg) were commonly active. These two species have not been recorded before and were not recovered at all from any host plant at Ukiriguru. However, a closely related

species, Enicospilus sp? communis (Szépl.) was recorded in Uganda (Coaker, 1959) in larvae collected from cotton. Between 1983 and 1985, Cardiochiles spp. were repeatedly recovered from H. armigera larvae collected on Cleome plants in the middle of Serengeti National Park. These records indicate long range migration of the pest adult moths and its natural enemy complex. In recent years there has been great speculations of natural enemy migrations because large numbers of natural enemies are recorded from light trap catches (Greathead and Girling, 1981). The two records at Ukiriguru of Enicospilus spp. could be due to long range migration but more research will be needed to find the relationship between different climatic factors and natural enemies found in light traps.

Despite seasonal variations in the level of parasitism and species abundance, Charops sp. and Cardiochiles spp. were the most commonly recorded species on host plants throughout the four seasons. These two species were also recorded as the most common H. armigera parasites in Uganda (Coaker, 1959). Moreover, the most commonly recorded larval parasites on each host were as follows (Fig. 32).

Host plant	Parasites
<u>Cleome</u> sp.	<u>Charops</u> sp; <u>Cardiochiles</u> spp.
Tomatoes	<u>Charops</u> sp; <u>Cardiochiles</u> spp.
Maize	<u>Apanteles diparopsidis</u>
Sorghum	<u>A. diparopsidis</u> , <u>Palexorista laxa</u>
Cotton	<u>Cardiochiles</u> spp; <u>P. laxa</u>
Chickpea	<u>Charops</u> sp; <u>Paradrino halli</u> ; <u>P. laxa</u>

The level of parasitism as presented in this study may have been underestimated (van Driesche, 1983) because

- a) The percent parasitism does not take into account those individual larvae which died due to the impact of the parasitoid adults either because they were paralysed by the parasitoid but oviposition did not occur, or they died from trauma from parasitoid oviposition, or their normal behaviour was changed by the presence of the parasitoid and thus might have suffered higher mortality from predation and/or environmental conditions.
- b) The presence of larval diseases in the population may have led to the loss of parasitized larvae (Negrón and Riley, 1985). Bacillus thuringiensis for example, has been found to have some adverse biological effects on parasites and predators exposed to it (Salama, et al, 1982). Most larval diseases will kill the larvae and the parasite will fail to develop and emerge because it does not feed on dead tissue.
- c) Parasitism may change the behaviour of the host such that it may not be available for sampling. For example, Cardiochiles spp. cause premature prepupal stage in H. armigera larvae and these are likely to drop off the plant into the soil to pupate and thus escape being sampled. This will result in underestimation of the impact of the parasite on the pest population and the overall percent parasitism.
- d) Premature removal of larvae before completion of parasitism may

result in a biased level against the full potential of a parasite. For example, tachinids attack the older larvae and where small and medium larvae were sampled they escaped being parasitised by the tachinid.

Therefore, the percent parasitism presented is general and may not be entirely adequate for evaluating the impact of parasites on the different larval stages of the pest as may be important in improving biological control strategies. Thus further research work is needed.

4.1.5.4. Other mortality factors - Predation of H. armigera under field conditions was very difficult to assess because most predators are very mobile and also attack a wide range of prey. However, Chrysopa eggs and larvae, coccinellids, syrphid larvae, frogs, preying mantids and ants were regularly recorded on all the host plants. Two species of Chrysopidae were recorded in the area and these were identified by the Commonwealth Institute of Entomology (S. Brooks) as Anisochrysa boninensis (Okamoto), whose larvae carry debris on their back, and Chrysoperla congrua (Walker). Chrysopa larvae prey on eggs and larvae of H. armigera up to the 3rd instar stage (Reed, 1965b). Of the coccinellids, the most commonly encountered were Cheilomenes lunata (F.); C. propinqua (Muls.); C. sulphurea (Oliv.) and Exochomus flavipes (Thumb.). Birds, especially Quelea quelea spp. which are important pests of grain sorghum may also feed upon the larvae of H. armigera. Two unidentified species of plant frogs were very common on cotton, maize and sorghum plants.



Plate 3. H. armigera larvae feeding on a sorghum head: larvae migrating to other plants using leaves as bridges.

Predatory frogs on Heliothis spp. have been recorded by other workers (Reed, 1965b; Room, 1979).

Cannibalism can be important in H. armigera larvae from the 3rd instar onwards. On maize, larval cannibalism is considered to be the most important mortality factor particularly on the late instars (Lincoln, et al; 1967). Larval density per plant from the 1st to 3rd instars, when they feed on the silk, was observed to be very high, with up to more than 10 larvae in a cob. However, density decreased with older instars most probably due to cannibalism. The older instar larvae usually attempt to enter the cob and in doing so come in contact with other larvae and this often leads to cannibalism. Although larval cannibalism on sorghum can occur, it is considered unimportant (Kinzer and Henderson, 1968). The population per sorghum ear may be particularly high even of mature larvae stages, and often a range of different instars are found feeding on the same ear. When large populations of larvae occur on sorghum, several behaviour mechanisms were observed. First larvae tried to avoid each other either by crawling away and/or in the case of small instars, by dropping and then suspending from a silken thread. Secondly, medium to older instar larvae migrate from one plant to another using the leaves as a bridge (Plate 3). Although larval migration on sorghum could be a means of reducing intra-specific competition, it also increases the level of predation and parasitism as such larvae are more easily attacked.

Adverse weather effects, in particular the mid season dry

spells, have indirect and direct effects on the pest population. In dry weather, host plants grow less vigorous and therefore become less attractive for oviposition. Poorly growing plants will be nutritionally poor and this may not only cause reduced rates of larval growth but may also result in larval mortality (Hardwick, 1965). When the plants are under moisture stress some larvae would attempt to migrate in search of a more suitable host plant and this will expose them more directly to the adverse weather conditions and to natural enemies, thus leading to low larval survival rate. Therefore, although an initial heavy attack on a particular host may occur, the total pest population may be small if the host is nutritionally poor (Lincoln, 1972). For example, the pest population decline in February 1983-84 (Fig. 10) and in March 1984-85 (Fig. 11) was no doubt a consequence of prolonged dry weather in that period of the year. Rens (1977) reported a pest population decline to zero on cotton in Kenya during a dry spell.

Heavy and windy rains, especially during the heavy rains in March - May, can reduce the pest levels because eggs and small larvae can be easily dislodged (Hardwick, 1965; Coaker, 1959).

5 THE OVERALL DYNAMICS OF H. ARMIGERA IN THE STUDY AREA

5.1 The relative attractiveness of different hosts

With the exception of chickpea and Cleome which are attractive to H. armigera ovipositing moths from the seedling stage, all of its hosts become attractive at flowering stages (Parsons, 1939, 1940b; Pearson, 1958; Hardwick, 1965). To establish the trend of susceptibility for some of the host plants in the study area, the feeding preferences of H. armigera larvae were assessed under field conditions at each sampling date for all the hosts included in the study.

On Cleome, a total of 997 larvae were observed. 3.4% of the larvae were recorded feeding on leaves, 95.9% on flowers and 0.7% on pods. H. armigera lays eggs on preflowering Cleome in early October but it is more suitable at the flowering stage. The weed flowers throughout the year but remains attractive from October to the end of June. In three seasons out of four no larvae were found on Cleome between July and mid September despite the fact that some plants were flowering this period. Earlier work in the same area (Reed, 1965b) showed that H. armigera could only be found on Cleome between October and January. The few larvae found on this host during the dry season, July - September, grew slowly and most failed to pupate. This could be due to factors inherent to the plant, possibly chemical or physical nature, and is worth further investigation.

A total of 770 larvae were observed on tomatoes. 24.1% were

feeding on leaves, 3.1% on flowers and 72.7% on fruits. Beeden (1976) found that young larvae feed on flowers and head fruits with a few feeding and boring into stems, whereas older larvae prefer firm green fruits. In the USA, H. zea adults were observed to prefer to oviposit on the underside of tomato leaflets in the middle plant region and the early instars feed primarily in the calyx area, whereas more mature larvae attack fruits at all stages of development (Snodderly and Lambdin, 1982). Tomatoes are mostly susceptible to H. armigera infestation at flowering and fruiting stage and most larvae were found on it at these stages.

On maize, 793 larvae were observed; only 1.2% were feeding on tassels (male flowers), 94.6% on the silks, and 4.1% on the cob tips. Many of H. armigera eggs were found on the silks. Similar observations have been recorded by other workers (Valentine, 1955; Coaker, 1959; Reed, 1965b; Lincoln, et al, 1967; Beeden, 1976). Usually maize tassels before silking and although a low infestation could occur at tasselling, the main population would be expected at silking. After initial infestation, H. armigera larvae of various instars were found on cobs up to the dough stage. Therefore, the attractive stage of maize for oviposition at least in varieties at Ukiriguru is relatively long compared to sorghum, but short compared to cotton and tomatoes. Valentine (1955) made similar observations at Ilonga. He observed that egg laying continued for about 3 weeks after the first silks began to appear and that larvae could be found feeding on the silk and cobs for 5 to 6 weeks from the initial infestation. Most of the larvae found on the cob tips were feeding

on the grains at the tip which contribute little to total grain yield. Similar observations have also been made in Northern Nigeria (Beeden, 1976).

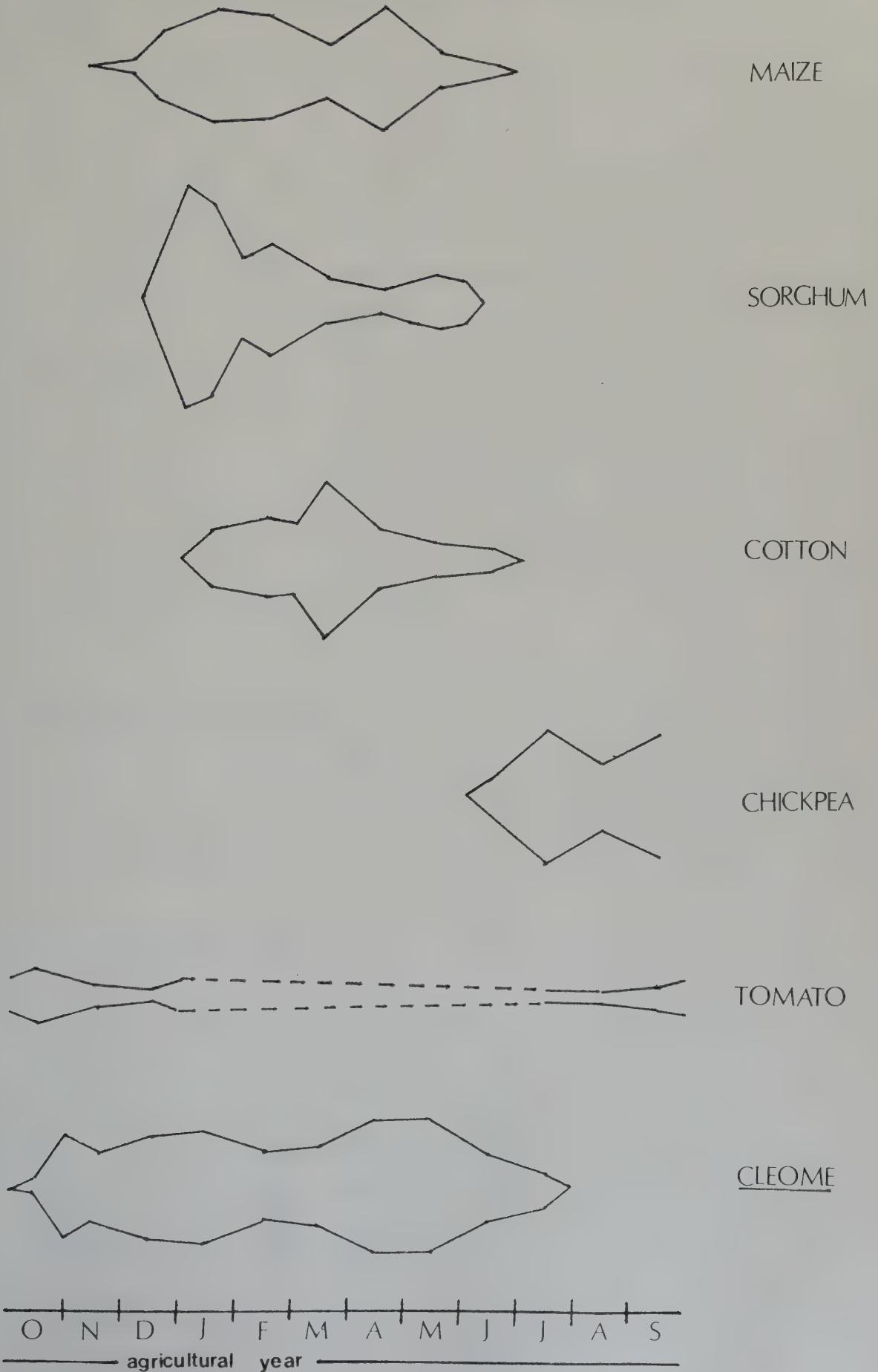
Sorghum is attractive to H. armigera infestations at flowering (Peat, 1956; Kinzer and Henderson, 1968), and since only the heads are attacked, feeding preference was not assessed. Egg laying begins just as the heads emerge and before much pollen has developed (Parsons, 1940b; Negrón and Riley, 1985). Early instar larvae become more abundant as soon as the pollen becomes visible. The small larvae feed on the anthers as they are unable to penetrate grains (Hackett and Gatehouse, 1978). For any one crop of sorghum, the attractive stage for H. armigera oviposition is thus very short, and unless there is sequential sowing of the crop, only one generation can occur.

H. armigera can attack cotton at the vegetative phase, but peak oviposition occurs at the flowering stage and declines as the plant ages and flowers less profusely (Parsons, 1940b; Coaker, 1959; Adkisson, et al; 1964; Reed, 1965b; Beeden, 1976), also Figures 2, 12 and 33.

The seasonal population changes of H. armigera on its alternative host plants (Fig. 33) is a very generalized one and the timing and level of the pest population build up may vary depending on the timing, amount and distribution of rainfall in the season.

Fig 33

Diagrammatic representation of the seasonal population abundance of H. armigera on its individual plant hosts.



5.2 The relative abundance and productivity of the hosts of

H. armigera

In order to establish the relative importance of the different host plants in the study area the relative abundance of the hosts was assessed between December 1983 and August 1985 to cover the different seasons. This was done by observations made from a motorcycle over a total distance of 10 to 16 km. Every minute an estimate of the host plants on the basis of presence or absence was made within approximately 100m on the left and right side of the road. Whenever Cleome was recorded, its density per m² was assessed by counting the actual number of plants in a random 1m² area where the Cleome was growing. This was repeated on 10 different occasions. The data was used to calculate population indices as described below. Data from 25 March 1984 are used below as an example.

a) The abundance of host plants

Total number of observations made = 26

The frequency of occurrence of individual hosts was as follows:

Maize 5; Sorghum 1; Cotton 4; Tomato 1; Cleome 10.

i) % Relative abundance (%RA):

Maize	=	$\frac{5}{26}$	x100	=	19.2
Sorghum	=	$\frac{1}{26}$	x100	=	3.8
Cotton	=	$\frac{4}{26}$	x100	=	53.8
Tomato	=	$\frac{1}{26}$	x100	=	3.8
<u>Cleome</u>	=	$\frac{10}{26}$	x100	=	38.5

Table 14. Relative abundance of alternative hosts of H. armigera
at Ukiriguru December 1983 to August 1985 : Host plant
% contribution

Date	Maize	Sorghum	Tomato	Cotton	Chickpea	<u>Cleome</u>
18 Dec 83	66.6	2.1	6.2	0.0	0.0	25.0
29 Dec 83	63.0	3.7	7.4	0.0	0.0	25.9
4 Mar 84	37.5	0.0	2.1	43.7	0.0	16.7
25 Mar 84	16.1	3.2	3.2	45.2	0.0	32.3
6 May 84	17.3	5.8	3.8	53.8	0.0	19.2
10 Aug 84	0.0	0.0	73.4	0.0	6.6	20.0
28 Nov 84	25.0	0.0	18.7	0.0	0.0	56.2
6 Dec 84	46.1	0.0	19.2	0.0	0.0	34.6
31 Dec 84	51.3	24.3	10.8	0.0	0.0	13.5
21 Aug 85	0.0	0.0	76.5	0.0	5.8	17.6

Table 15. Mean monthly larval density per plant in 1984.

Date	Maize	Sorghum	Tomato	Cotton	Chickpea	<u>Cleome</u>
March	0.12	0.01	-	0.24	0.00	0.25
May	0.25	0.10	-	0.15	0.00	0.50
August	0.00	0.0	0.05	0.00	0.06	0.00
November	0.00	0.00	0.01	0.00	0.00	0.36
December	0.16	1.70	0.05	0.00	0.00	0.29

Table 16. Population indices for the period March to December 1984

Date	Maize	Sorghum	Tomato	Cotton	Chickpea	<u>Cleome</u>
March	4.42	0.02	-	14.09	0.00	7.75
May	7.03	0.95	-	13.56	0.00	15.62
August	0.00	0.00	1.95	0.00	0.18	0.04
November	0.00	0.00	0.06	0.00	0.00	12.63
December	11.48	34.76	1.08	0.00	0.00	10.03

The %RA figures were then adjusted to give the percentage contribution of the attractive hosts to the overall host plant population (Table 14).

$$\text{ii) \% Contribution of X} = \frac{\% \text{RA}}{\text{Grand Total \% RA}} \times 100$$

Thus, on the 25 March, the proportion of the different hosts were as follows:

Maize	=	$\frac{19.3}{119.2}$	x100	=	16.1
Sorghum	=	$\frac{3.8}{119.2}$	x100	=	3.2
Cotton	=	$\frac{53.8}{119.2}$	x100	=	45.2
Tomato	=	$\frac{3.8}{119.2}$	x100	=	3.2
<u>Cleome</u>	=	$\frac{38.5}{119.2}$	x100	=	32.3

b) Pest population index (P.1.)

P.1. = mean larvae per plant x % RA of host plants. Using the mean monthly larvae density per plant in Table 15, which has been extracted from Appendix 3, the population indices in Table 16 were then calculated. Whenever the survey was done twice in a month a mean of the % RA for that month was calculated. Plant densities for each individual host were taken during the season. The crop plant densities per unit area were not expected to vary as the season progressed because farmers used standard spacing. However, the plant density per unit area of land for the weed varied within the season, mostly due to changes in weather. It was therefore necessary to use the respective plant densities as obtained during the field counts.

Table 17. Absolute H. armigera larval densities on its different host plants for the period March to December 1984.

Date	Maize	Sorghum	Tomato	Cotton	Chickpea	<u>Cleome</u>
March	13.3	0.1	-	70.4	0.0	14.7
May	21.1	3.8	-	67.8	0.0	50.0
August	0.0	0.0	9.7	0.0	1.4	0.0
November	0.0	0.0	0.3	0.0	0.0	27.8
December	34.4	139.0	5.4	0.0	0.0	33.1

The average plant density per m² obtained from direct plant count on farmers fields were as follows:

<u>Host plant</u>	<u>Plant density per m²</u>
Cotton	5
Sorghum	4
Maize	3
Chickpea	8
Tomato	5
<u>Cleome</u>	1.9 in March
	3.2 in May
	1.2 in August
	2.2 in November
	3.3 in December

Using the plant density figures above, the population indices in Table 16 were further used to estimate absolute population densities of the pest population (Table 17). Thus, the relative population densities in March were as follows:

Maize:	4.42 x 3	= 13.3
Sorghum:	0.02 x 4	= 0.1
Cotton:	14.09 x 5	= 70.4
Chickpea:	0 x 0	= 0.0
<u>Cleome:</u>	7.75 x 1.89	= 14.6

5.2.1 Seasonal changes in pest population in relation to different host plants, 1984.

During the heavy rains in March, cotton was not only the most

abundant host but it was also at peak flowering and therefore attracted a notably heavier H. armigera infestation than the other hosts (Tables 16 and 17).

By May the rains had declined and the cotton crop was maturing and therefore less attractive to ovipositing moths because the nutritive value of the flowers has been shown to decline as the plant ages (Hardwick, 1965). During this time, some maize and sorghum were still attractive to ovipositing adult moths but Cleome was flowering most profusedly and therefore attracted heavier infestations than all the other hosts (Table 16). However, since cotton was still relatively more abundant than other hosts in May in terms of absolute numbers, it was still the main source of H. armigera larval population (Table 17). Observations at Ukiriguru during April and May over the past four seasons has shown maize to have more H. armigera eggs and larvae than cotton. Maize has been shown to be more attractive to H. armigera than cotton where both crops occur (Bebbington et al, 1953; Peat, 1956; Coaker, 1959; Smith and Bradley, 1962). It is therefore possible that in the absence of diversionary alternative hosts the infestation level in cotton would have been even higher and therefore more damaging.

The larval population of H. armigera during the dry season was generally low and associated with fewer suitable alternative hosts. During the dry season the proportion of suitable available hosts declined and by August only tomato and chickpea were infested (Table 15). Chickpea in particular, can be heavily infested and the level

of infestation tends to increase as plant density increases. However, at Ukiriguru the relative abundance of chickpea is less compared to tomatoes because the total acreage under the crop is relatively small and the fields are isolated, hence the low productivity of chickpea (Tables 16 & 17). Chickpea has been reported in many parts of Africa as an important host of H. armigera (Parsons, 1940b; Valentine, 1955; Pearson, 1958) but it is not a host of the pest in Northern Nigeria (Beeden, 1976); and was never reported by Reed (1965b) in WCGA; yet the crop has been in the area since 1932 (Section 1.2.4).

At the end of the dry season, Cleome would be the first to be colonized as soon as the first rains begin. This weed attracts ovipositing moths from the vegetative phase, and being relatively more abundant than either maize and tomatoes, generated a notably heavier larval population (Tables 16 & 17). By December, both maize and sorghum had started flowering and therefore attracted ovipositing H. armigera moths. Despite three times as much maize in flower compared to sorghum, the level of infestation on sorghum was about 11 times heavier than on maize (Table 15). In December, sorghum carried an overall heavier H. armigera larval population than all the other alternative hosts (Table 16 & 17).

5.2.2 The role of the different hosts in the annual cycle of H. armigera

The increased popularity of chickpeas in the dry season (Section 1.2.4) may be an additional factor that helps to explain the present

status of H. armigera in Western Tanzania. According to Reed (1965a) virtually no host plants of H. armigera were available during the dry season during which time the pest diapaused as pupae and emerged at the beginning of the short rains in October. The recent studies has shown that the pest population survives on chickpeas and tomatoes during the dry season. So, these two hosts may have had a significant impact on the proportion of the pest population which enters diapause. The level and pattern of pupae diapause observed over the study period (Table 23) was very low and did not show a specific trend (pupal diapause will be discussed under Section 6).

Throughout the study period, the first H. armigera larval generation on chickpeas overlapped the last generations on Cleome and occasionally that on cotton and maize. Thus, Cleome forms a bridge between the rainy season crops and chickpeas. Cleome is also a host of the pest throughout the year except July to September (Fig. 12 and 33).

The flowering of maize and sorghum in December and January increases the number of alternative hosts and being more abundant (Tables 16 & 17) than Cleome, generates a higher pest population. The two crops are continuously available in varying proportions between December and May.

Cotton is not only the main host between February and May but it is the only drought tolerant host in the system which is characterized by having a long flowering period, and therefore provides a long period for the pest population.

5.2.2.1 The role of Cleome, chickpeas and tomatoes in the dynamics of H. armigera in the study area, 1981-82 to 1984-85

5.2.2.1.1. Cleome - H. armigera feeds and breed on this host only from October to July (Fig. 12). The weed is not only a reservoir for the pest population but also for a wide range of H. armigera natural enemies. Almost all the species of larval parasites and pathogens were recorded on this wild host although their abundance varied during the season relative to other host plants. Thus, natural enemies were particularly abundant on the weed early in the season, October - December (Fig. 32) before the cultivated host plants reached attractive stages for oviposition by H. armigera adults. In contrast, during the cropping season, the level and abundance of parasites in particular, remained low although no doubt important as a reservoir. Many of the parasitic species recorded on Cleome in relatively low numbers early in the season occurred in high numbers on their preferred host plants.

Cleome flowers profusely and may provide nectar and pollen to many adult parasites and predators, and also to H. armigera adults early in the season before the crops begin to flower. Many adult parasites require nectar and pollen to complete their life cycle, and weed flowers are often important natural sources (van Emden, 1963; 1965; Perrin, 1975; Altieri, van Schoonhoven and Doll, 1977; Zandstra and Motooka, 1978). If Cleome is maintained at a low density adjacent to field crops it may be a vital host in the life cycle of the pest and its natural enemy complex.

Cleome may also be a reservoir of the pest population for cotton as insecticide spraying of the crop increases. Although there is no record of insecticide resistance in H. armigera on cotton in Tanzania, continued use of pesticides may lead to the development of a resistant strain. Moth populations originating on Cleome may provide a good 'diluent' of susceptible strain to any resistant strains that may develop and thus prolong the life of the insecticide.

Insecticide application on cotton usually destroys large numbers of natural enemies, so at the end of the spraying period the late season build up of the pest population on the crop could be very damaging in the absence of its natural enemies. Hence the late season build up of larval parasites on cotton may depend on the Cleome reservoir of natural enemies. Thus, Reed and Robertson (1963) noted that at Ukiriguru, over 50% of H. armigera larval parasitism occurred after mid April and therefore, despite heavy egg laying after the end of the spraying programme, little damage occurred on the crop because few larvae survived parasitism.

Finally, Cleome forms a bridge between the rainy season crops and the dry season crops, chickpea and tomatoes (Section 5.1.3).

5.2.2.1.2 - Tomatoes and chickpea - These contribute significantly to the annual population dynamics of the pest because they are the only important dry season hosts (Section 5.1.3). Larval parasites are uncommon on both crops but are possibly significant because these

crops enable the pest and its natural enemy complex to survive the dry season, thus bridging the gap between the dry and short rain seasons. Reed (1965a) reported that during the dry season, pupal diapause breaks the association between H. armigera and its natural enemies and can result to a rapid build up of the pest early in the season in the absence of natural enemies. However, the current study has shown continuous activity of the pest population and its natural enemies, a similar situation reported in Uganda by Coaker (1959). The observed changes in the biology of the pest population could be due to the recent increased popularity of tomato production during the dry season and the expansion of the area under chickpeas.

To date, insecticides are not used on tomatoes and chickpea to control H. armigera. Thus, the adult population may build up on these two crops and provide an important source of pesticide susceptible adults which may delay the build up of insecticide resistant strains in the pest population on cotton.

5.3 Impact of parasitism and diseases on population dynamics of H. armigera.

The viral disease, in particular a NPV, causes death most frequently in the first to the third instar larval stages, and less in fully grown larvae (Whitlock, 1973; Negrón and Riley, 1985). Infected larvae die quickly (Coaker, 1958; Whitlock, 1973), and the impact of the disease on the pest population is very rapid and can easily cause collapse of relatively large infestations, in particular on maize and Cleome where the pathogen occurs naturally. An

experiment was conducted in the laboratory using larvae killed by the virus. These were ground and mixed with distilled water and the suspension sprinkled onto chickpea leaves which were then fed to first instar larvae (one day old larvae). Early instars of H. armigera larvae are not cannibalistic and therefore they were fed in groups of 100 - 200, and the contaminated leaves used only once. The experiment involved 1300 first instar larvae in 4 replications and showed that this crude preparation was toxic. Larval mortality began after 24 hours of feeding and by day four over 50% of the larvae were dead. After six days all larvae had died. According to Whitlock (1973), where NPV occurs naturally, about 65% of the mortality occurs within the first 9 days after hatching.

In contrast, larvae with bacterial diseases usually died at later instars, often when fully grown. Although in most cases infected larvae had reduced feeding and growth rate, feeding and damage to the plant continued to occur. Thus, although bacterial diseases were more widespread among larvae on different host plants, these do not have an immediate impact.

In conclusion, the NPV is seemingly the most suitable pathogen for exploitation as a control measure since the disease may eliminate the pest before it can cause much damage to the crop. However, due to differences in the natural distribution of the pathogen it may be more successful to introduce or augment NPV on certain host plants than on others, but this needs further investigation (Nyambo, 1984).

Parasite activity was greater on some of the host plants than others. Overall, the tachinids affect only the last instars which also complete their feeding and therefore do not significantly reduce damage to the plant but will only affect the size of the effective moth population. Therefore, although tachinids were particularly abundant on sorghum and chickpea, total yield losses on these crops can still be considerable when the pest is abundant. In contrast, the braconids and ichneumonids provide some control on current pest populations because they attack and kill small and medium instars before such larvae can cause heavy damage to the crop.

Apanteles diparopsidis Lyle which was notably abundant on sorghum and maize, attack the first larval instar, and the parasite pupa emerge from the 2nd larvae host instar. The adults emerge within about 5-8 days after pupation. However, the species was rather sporadic in occurrence (Table 16¹/₂).

C. (Microchelonus) curvimaculatus (Cameron) possibly attack 1st and 2nd instar larvae because the parasite pupa emerged from the 2nd and 3rd instars. The adult emerged from the pupa within about 11 days after pupation.

Charops sp. probably attack small larvae because the pupa emerged from the 3rd and 4th instar larvae. The majority of the species were recovered from larvae collected as 2nd instars. C. sp. nr. spinitarsus, a related species which has been recorded in Northern Nigeria (Beeden, 1976) causes larval mortality from the 3rd through to the 6th instar.

Cardiochiles spp. caused mortality at the 2nd through to the 4th instar larvae. Both species caused premature pre-pupa development in the host larvae which stopped feeding. According to Pearson (1958), Cardiochiles spp. attack 2nd and 3rd instars whereas its related species in the USA, C. nigriceps has been reported to attack 1st through to 5th instars of H. virescens (Lewis and Brazzel, 1966). The species were very common larval parasites on all the hosts.

Paradrino halli (Curran) attacks large larvae and the parasite pupa emerge from the pupa stage of H. armigera. Parasitized larvae had a prolonged pupae duration which means that the parasite takes a long time to reach maturity. Only one pupa emerged per host, and the pupation period lasted 9-11 days. Robertson (1973) reported a puparial period of 10-13 days at Ukiriguru. Similarly, Palexorista laxa (Curran) attacks large larvae and the parasite pupae emerged at the 5th to the pre-pupae stages. Several pupae emerged from a single host larvae and the size of the pupae tended to decrease as the number of pupae per host increased. Pupal period varied between 7-16 days after leaving its host (Robertson, 1973).

Thus, although several important larval parasites are active on the pest population and their effectiveness may be improved by conservation and enhancement, many of them are far from ideal for the control of H. armigera as they have several alternative insect hosts (Table 18). However, they require further study on their biology and ecology before their value can be adequately assessed.

Table 18. African records of parasitoids recorded from H. armigera larvae at Ukiriguru 1980-85.

Parasites	Host plants 1980-85	Previous records from <u>H. armigera</u> on cotton etc in Africa	Alternative lepidopterous insect hosts of the parasitoid in Africa			
			Insect host	Host plant	Country	Authority
HYMENOPTERA Braconidae <u>Apanteles diparopsidis</u>	Sorghum*, Maize* Cleome, Cotton, Tomato		<u>Earias biplaga</u>	Cotton	Ukiriguru- Tanzania Kawanda- Uganda Congo Zambia Nigeria Zimbabwe Sudan	Greathead (1966) Greathead (1966) Pearson (1958) CIBC Cat. CIBC Cat. Broudryk(1971) Pearson (1954)
			<u>Diparopsis watersi</u> <u>Pectinophora gossypiella</u>	<u>Hibiscus</u> sp Cotton Cotton	Kawanda- Uganda	Taylor (1936)
<u>Apanteles</u> sp (<u>vitripennis</u> sp. group)	<u>Cleome</u> , Maize					

* Most Common

Table 18 (Continued)

Parasites	Host plants 1980-85	Previous records from <u>H. armigera</u> on cotton etc in Africa	Alternative lepidopterous insect hosts of the parasitoid in Africa			
			Insect host	Host plant	Country	Authority
<u>Cardiochiles</u> sp) <u>Cleome*</u> , Cotton*)) Tomato*, Maize)) Sorghum, Chickpea	Reed (1965) Coaker (1959) Greathead (1966) Robertson (1973)				
<u>C. sp (nr. C. trimaculata)</u>						
<u>Chelonus</u> (<u>Microchelonus</u>) <u>Curvimaculatus</u>			<u>Pectinophora gossypiella</u>	Cotton	Tanzania	Le Pelley (1959)
	Sorghum*, Maize, Cleome, Cotton Chickpea	Coaker (1959)	<u>Phthorimaea operculella</u>	Potato	Somalia Ethiopia Zimbabwe	CIBC Cat Legner & Thompson (1977) Mitchell (1978)
					Zambia	Cruickshank et al, (1973)
					S. Africa S. Africa	Broodryk (1969) Watmough et al.(1973)
<u>Meteorus</u> sp	Cotton	Reed (1965) Roome (1971) Beeden (1976)				

* most common

Table 18 (Continued)

Parasites	Host plants 1980-85	Previous records from <u>H. armigera</u> on cotton etc in Africa	Alternative lepidopterous insect hosts of the parasitoid in Africa			
			Insect host	Host plant	Country	Authority
<u>Ichneumonidae</u> <u>Charops</u> sp.	Cotton*, Chickpea*, Tomato*, Maize, Sorghum, <u>Cleome*</u>	Parsons (1940) Coaker (1959) Reed (1965) Greathead (1966) Nyiira (1970) Robertson (1973) Beeden (1976)	<u>Earias biplaga</u>	Cocoa	Ghana	Smith (1965)
			<u>Antigastra catalaunalis</u>	Sesame	Ivory Coast Ilonga-Tanzania	Alibert (1951) Robertson (1973)
			<u>Epigynopteryx stictigramma</u>	Coffee	Kenya	Leeuwangh (1965)
			<u>Orgyia mixta</u>	Softwood	Kenya	Austara & Migunda (1971)
			<u>Sylepta derogata</u> <u>Spodoptera exigua</u>	Cotton Maize	W. Nigeria Ilonga-Tanzania	Odebiyi (1982) Robertson (1973)
<u>Netelia</u> sp.	Cotton, Sorghum, Tomato, <u>Cleome</u> Maize	Reed (1965) Robertson (1973) Greathead (1966) Nyiira (1970)	<u>Earias biplaga</u> & <u>E. insulana</u>	Cotton	Ivory Coast	Pearson (1958)
					Ilonga-Tanzania	Greathead (1966)
				Cotton & <u>Hibiscus cannabinus</u>	Ilonga-Tanzania	Robertson (1973)

*most common

Table 18 (Continued)

Parasites		Host plants 1980-85	Previous records from <u>H. armigera</u> on <u>cotton</u> etc in Africa	Alternative lepidopterous insect hosts of the parasitoid in Africa			
				Insect host	Host plant	Country	Authority
<u>Pristomerus</u> sp		Cotton, Tomato, Maize, Sorghum	Parsons (1940) Greathead (1966) Robertson (1973)	<u>E. biplaga</u>	Cotton <u>Hibiscus</u> <u>cannabinus</u> & Cotton) <u>Hibiscus</u> sp)	Uganda	Greathead (1966)
				<u>E. biplaga</u> & <u>E.</u> <u>insulana</u> <u>phthorimaea</u> <u>operculella</u>	Potato	Ilonga- Tanzania Zimbabwe	Robertson (1973) Broodryk (1971)
Diptera Tachinidae <u>Palearista</u> <u>laxa</u> [<u>Drino</u> <u>imberbis</u> (<u>wied.</u>)]		Sorghum* Chickpea* Cotton* Cleome, Maize Tomato	Reed (1965) Roome (1971) Beeden (1976) Robertson (1973)- Lazarević (1971)	<u>Antigastra</u> <u>catalaurealis</u>	Sesame	Zimbabwe	Mitchell (1978)
				<u>Plusia acuta</u> <u>Walker</u> <u>Earias biplaga</u>	Maize & sunflower Cotton & <u>Hibiscus</u> <u>cannabinus</u>	Nigeria Ilonga- Tanzania	Cruickshank, et al, (1973) Chadha (1974) Robertson (1973)
Diptera Tachinidae <u>Palearista</u> <u>laxa</u> [<u>Drino</u> <u>imberbis</u> (<u>wied.</u>)]		Sorghum* Chickpea* Cotton* Cleome, Maize Tomato	Reed (1965) Roome (1971) Beeden (1976) Robertson (1973)- Lazarević (1971)	<u>Plusia acuta</u> <u>Walker</u> <u>Earias biplaga</u>	Maize & sunflower Cotton & <u>Hibiscus</u> <u>cannabinus</u>	Ilonga- Tanzania Ilonga- Tanzania	Robertson (1973) Robertson (1973)

* most common

Table 18 (Continued)

Parasites	Host plants 1980-85	Previous records from <u>H. armigera</u> on <u>cotton</u> etc in Africa	Alternative lepidopterous insect hosts of the parasitoid in Africa			
			Insect host	Host plant	Country	Authority
<u>Paradrino</u> <u>halli</u> [<u>Sturmia</u> <u>halli</u> (Curr)]?	Chickpea*, Cotton, <u>Cleome</u> , Tomato <u>Sorghum</u> , Maize	Greathead (1966) Roome (1971) Robertson (1973)				

* most common

In conclusion, larval parasitism and diseases are important mortality factors on H. armigera and although these two factors may not prevent the pest population from reaching economically damaging levels, they do play an important role in regulating the pest population. The level of diseases and parasitism (Table 19) are low but on individual host plants these can be very important in restricting population build up.

Table 19. Overall means of H. armigera larvae killed by diseases and parasites expressed as percentage of the total number of larvae observed from 1981-82 to 1984-85.

Mean of 4 seasons	% Diseased	% Parasitised	Total number of larvae observed
Oct	14.8	17.8	987
Nov	10.2	26.5	2053
Dec	23.9	20.1	2937
Jan	34.5	13.6	5985
Feb	34.6	10.5	2634
Mar	20.2	7.1	2732
Apr	25.9	5.7	2972
May	23.8	10.0	2658
Jun	17.4	9.4	2912
Jul	9.5	4.8	4392
Aug	13.0	3.8	3793
Sep	10.4	1.2	646

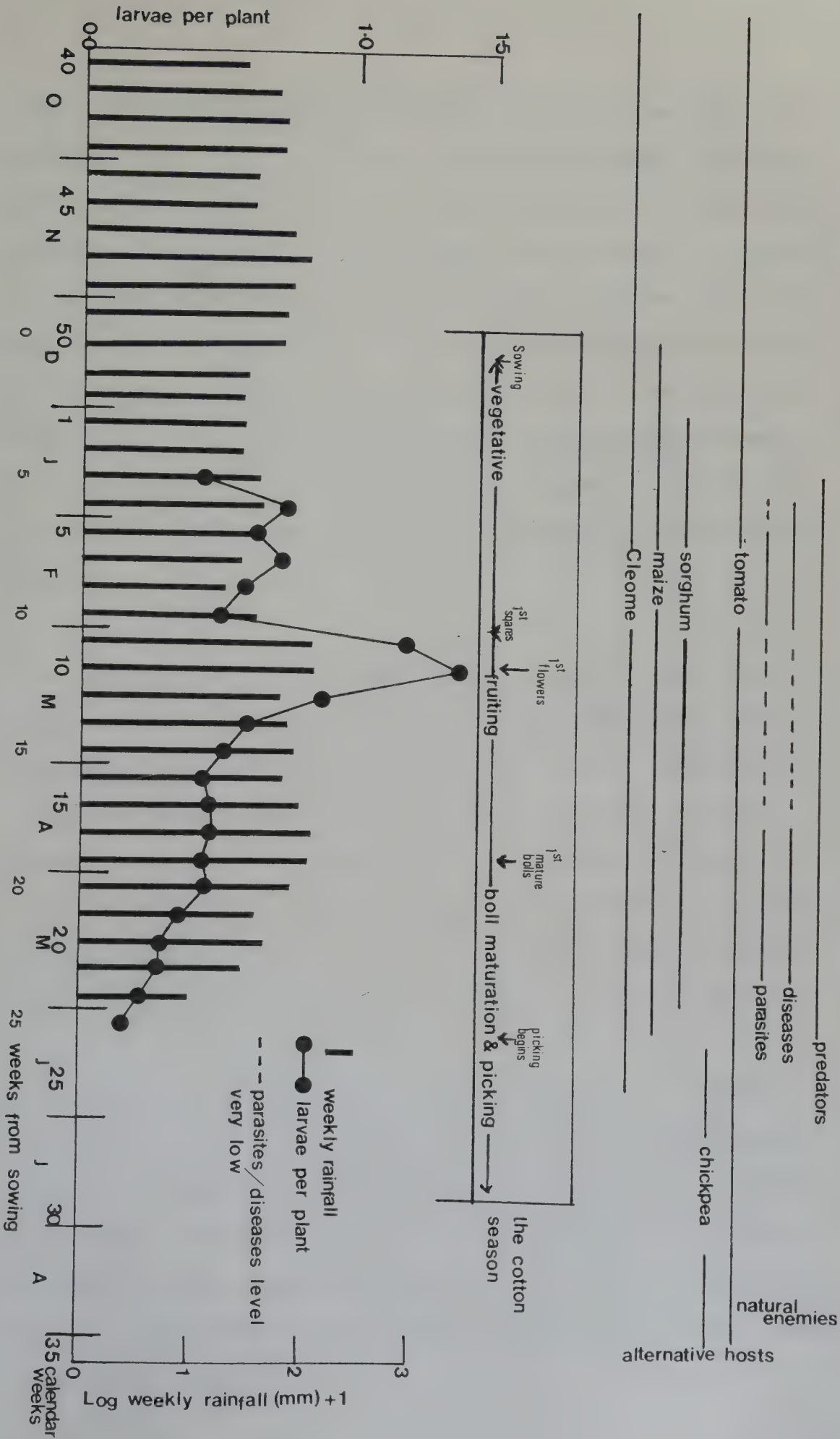
Thus, intensive ecological and biological studies are a prerequisite for successful improvement of the existing biocontrol agents; in particular formulation and application methodology of NPV pathogen (Nyambo, 1984) which can kill the small larvae before they cause heavy damage.

5.4 Intercrop relationship with emphasis on cotton

The study was carried out in a relay intercropping system practised by small scale farmers, which is characterised by the availability of different hosts with different susceptibilities all of which occur simultaneously but is complicated by considerable variation in the time of sowing. Although the attractive stages of the different hosts overlap to provide continuous susceptible hosts for H. armigera activity throughout the year (Figure 33), the host-plant interactions, either as camouflage or diversionary, are important in the management of the pest population on the target crop. H. armigera is a minor pest of maize and therefore maize could be considered a secondary host of the pest. Similarly, Cleome, being a weed, is also considered as a secondary host in particular during the main farming season, January to May, as it is relatively less abundant compared to the cultivated hosts. On sorghum, H. armigera can cause heavy grain losses and spraying is often necessary. However, H. armigera is the key cotton pest in Tanzania and can cause serious yield losses if uncontrolled.

Early in the season, the first two generations of the pest population build up on Cleome and later disperse onto maize and

Fig 34 *H. armigera* seasonal activity on cotton and the factors affecting the population changes in the crop.
Summary: 1981-82 to 1984-85.



sorghum in late December and early January (Figure 12). The generation developing from maize, sorghum and Cleome disperse to cotton in mid January or early February (Figures 7 to 11). Early season maize and sorghum is considered as a potential hazard to cotton in western Tanzania (Peat, 1957; Reed and Kayumbo, 1965; Reed and Kerridge, 1968). However, whether a heavy infestation will build up on cotton in January - February will depend on a number of factors (Figure 34). The summary of H. armigera pest population changes and the interacting factors in cotton (Figure 34) demonstrates the chain of events in the population dynamics of the pest on its alternative hosts.

The availability of sorghum and/or maize at the flowering stage during January - February will definitely reduce the level of infestation on cotton (Figures 7 to 11). Evidence from work done elsewhere shows that H. armigera adults oviposit on maize in preference to cotton (Parsons and Uliyett, 1934; Valentine, 1955; Peat, 1956; Pearson, 1958; Coaker, 1959; Reed, 1965b). In addition, the pest population will disperse or distribute over a wide host plant area, thus reducing the overall pressure on cotton plants.

Weather, notably the amount and distribution of rainfall, is very important. Favourable rainfall early in the season promotes good early growth of alternative hosts of the pest, but dry spells, particularly in December, January and February cause heavy stress on the plants causing rapid population decline, as reported by Reed and Kayumbo (1968), Percy (1974) and also recent observations in 1983-84 and 1984-85, (Figures 10 and 11).

The level and abundance of natural enemies on maize, sorghum, and Cleome early in the season will also determine the build up of the pest population on these hosts. Heavy larval mortality due to pathogens on maize and Cleome, and parasitism on sorghum and Cleome will reduce the size of the effective population originating on these hosts.

After the initial infestation on cotton, the population builds up in the crop, and although re-infestation from alternative host plants occurs, the population in the crop perpetuates itself during the season, in particular between February and March when there is often less flowering maize and sorghum; and when Cleome is the only important alternative host (Tables 16 and 17). The population pressure in the cotton crop is often high in March and causes severe crop losses. However, the severity of the infestation depends on rainfall. For example, in 1983-84 (Figure 10) there was less than average rainfall and the pest population level was small because the plants were not growing vigorously. In contrast, in 1982-83 (Figure 9) good rainfall favoured the build up of a heavy infestation, on cotton in February and March.

In addition to Cleome, late maturing maize, late sown sorghum and ratoon sorghum begin to flower in April, and flowering extends to May. The availability of flowering maize and sorghum at this time of the season is advantageous to cotton farmers as the overall H. armigera population pressure is diverted away from cotton (Figures 8 to 11). Similar observations were made earlier at Ukiriguru (Peat,

Munro and Arnold, 1954; Peat, 1956; Smith and Bradley, 1962; Reed, 1964), and an upset in this cropping system could cause heavy losses to cotton in some years, particularly when a top crop is expected.

The late season build up of larval pathogens and parasitism may have no direct influence on the crop but will have an impact on the overall build up notably the generation that disperses to chickpea in June.

5.5 Prospects for forecasting pest occurrence on cotton from other hosts

Predicting the time of the initial infestation in cotton from other hosts was first attempted at Ukiriguru by Reed and Kayumbo (1965) based on the levels of the pest populations on maize in December and January that year. In South Africa, Morton (1979) suggested that maize tasselling be used to detect H. armigera oviposition on cotton, whereas in the Sudan Gezira, Topper (1978) suggested monitoring larvae in groundnuts to predict the timing of the first infestation in cotton. The objective of monitoring the pest population from the source is to improve timing and need for chemical control and thus optimize the use of insecticides. However, H. armigera is far from an ideal pest for monitoring from source because of its polyphagous feeding habit and because there is a tendency for the pest population to build in the crop after the initial infestation. Such build up is influenced by variable factors such as the growing conditions of the host plants, the weather and impact of natural enemies. Thus, whereas it may be possible to

predict the size and occurrence of the initial infestation from an alternative host, subsequent regular monitoring of the pest in the crop will also be required.

Maize is one of the alternative hosts on which the pest population may develop but on which it does not cause economic damage and since no control measures are needed, it was considered an ideal host for monitoring purposes.

In these studies, it was decided to monitor the level of the 5th and 6th instar larvae on maize because these final instars determine the size of the likely adult population which will disperse to other hosts. Monitoring for eggs and small instar larvae could give inaccurate information because heavy mortality may occur during the egg stage and small instar larvae and thus a heavy initial infestation may not necessarily result in a heavy build up of the adult pest population (Section 4).

5.5.1 Monitoring *H. armigera* 5th and 6th instars on maize to predict first infestation on cotton

The survey covered only two villages, Nyamle and Ngudama. Each was visited once a week and on the same day each week. On every visit, only maize cobs at the dough and/or approaching dough stage were examined for 5th and 6th instar larvae, and if found, were recorded and taken into the insectary for rearing to adult and for observations on parasitism and disease.

Subsequently, in order to check the validity of the prediction, counts of eggs and 1st and 2nd instar larvae on cotton was also monitored. The survey started in 1984 and was repeated in 1985.

During 1984, the survey began on the 16th of January (3rd week of the year) and continued to the end of February. The weekly level of abundance of the 5th and 6th instar larvae (Table 20) was very low largely because being a dry season, the overall pest population was notably low.

Table 20. Summary of 5th and 6th instar larvae monitored on maize from 16th January to 28th February 1984: Larvae per plant.

	Wk.1	Wk. 2	Wk. 3	Wk. 4
January	-	-	0.05	0.10
February	0.07	0.12	0.06	0.06

Larvae collected in week 3 pupated towards the last week of January (week 4) and the first adult emergence was recorded on the 12th of February (end of 6th week of the year). However, from the regular field monitoring for eggs and small larvae on cotton, the first infestation at the station on the early sown cotton at Nyashimba was recorded in the 5th week of the year (1st week of February), a week earlier than the first adult emergence in the insectary collection. Thus, monitoring for 5th and 6th instar larvae should have started at least a week earlier to be able to detect this first infestation on cotton.

During 1985, the survey began from the first week of January and continued weekly to the end of the month. The data is summarized in Table 21.

Larvae collected in the first week of January pupated in the 2nd week of the month and emerged as adults in the 4th week of January. From the data, the first infestation on early December sown cotton was recorded at the beginning of the 4th week of January, and therefore coincided with the first moth emergence of pupae formed in the 2nd week of January (Table 21).

Table 21. Summary of the 5th and 6th instar larvae monitored on maize during January 1985

Calendar Week	Larvae per Plant	Proportion of larvae surviving to adults (%)	Time of pupation	Time of adult emergence (Calendar week)
1	0.15	90.0	2nd week	4th to 5th
2	0.40	84.0	3rd week	5th to 6th
3	0.65	76.0	4th week	6th to 7th
4	0.32	71.0	5th week	8th
5	0.16	63.0	6th week	8th to 9th

Damage to the crop at the time of this first infestation was mainly to leaves and the early formed squares. First flowers on the early December sown cotton started to appear in the first week of February (Week 6) and this coincided with emergence of moths from pupae formed in the 3rd week (Week 3) of January. From the weekly egg and larvae monitoring on cotton, the level of infestation on the crop was very low at this time of the season mainly due to the dry weather conditions prevailing.

Over the past four seasons, the dates of initial cotton infestation in the study area has been as follows:

Year	
1982	4th week of January
1983	3rd week of January
1984	1st week of February
1985	4th week of January.

The first H. armigera infestation in cotton often occurs before the first flowers appear and is not considered of economic importance. The commercial cotton varieties are capable of compensating for early loss of fruiting points provided soil moisture and nutrients are not limiting. Thus, cotton spraying begins at first flower and continues throughout the critical period of the plant (Figure 2). No control measure is recommended for H. armigera infestation before cotton begins to flower.

The greatest benefit of a forecast would be to predict the timing of the early infestation as related to the appearance of the first flowers on the early sown cotton to be able to plan a control programme.

In conclusion, in order to provide a practical forecast of the first infestation on cotton from maize, the following factors need to be considered.

- a) The timing, amount and distribution of the short rains as this will affect the sowing and growth of sorghum and maize and also of cotton.
- b) The amount and distribution of rainfall in December and January which will influence establishment and growth of cotton plants as well as enable the maize crop to mature fully, both of which will affect the time of build up of the pest.
- c) The time of sowing of the early cotton. Thus, cotton sown in early December should begin flowering in early February and therefore monitoring for 5th and 6th instars on maize should be done in the 2nd week of January. The sowing dates may vary greatly from the last week of November to the end of December. However, this may be overcome if the sowing dates are sub-divided into one-week interval groups, thus enabling local forecasts to be made.
- d) The general weather trends in January and February which will very much affect the overall condition of cotton plants. For example, in 1982-83, January and February were relatively less dry and the pest population on cotton in February and March was

high, whereas in the 1983-84 season, the dry weather over the same period of time resulted in a low level of infestation on cotton.

6. MONITORING AND FORCASTING *H. ARMIGERA* USING LIGHT AND PHEROMONE TRAPS AND CROP INSPECTION

6.1 Introduction

Light traps have been used for a long time in many places to survey and forecast insect pest outbreaks. The successful survey and forecasting of Spodoptera exempta (Walker) in East Africa is a good example. At Ukiriguru, Reed (1965b) reported a successful forecast of a high H. armigera infestation on cotton in 1964 from a combination of light trap moth catches and egg and larvae counts on maize done in January that year. However, light traps as survey tools have limitations. First, light traps lack selectivity and therefore much skill is needed to sort and identify the catch. Secondly, light traps require a power source and this makes them unsuitable for isolated areas. Batteries or portable generators could be used but these are relatively expensive and may require regular maintenance.

In contrast, pheromone traps have advantages over light traps in that they are selective and catch only males and can be effective at very low pest population densities (eg. Croft, 1979) and often require less skill to operate and maintain. Thus, pheromone traps can be used even in very remote areas where light traps cannot be used. Of course there are further disadvantages common to both types of traps such as trap design, moth behaviour and meteorological factors which can influence catches in both traps.

It was therefore considered necessary to assess the efficiency of different H. armigera pheromone trap designs in order to identify a suitable simple trap that could be used to monitor the seasonal incidence of H. armigera in cotton with the objective of developing a system of correctly timed insecticide application based on a predetermined threshold. Furthermore, comparisons of adult moth catches in pheromone and light traps at Ukiriguru was made to assess the relative efficiency of the pheromone trap and also to provide information for more accurate interpretation of the pheromone trap data.

6.2 Trapping methodology

6.2.1 Light trap

The light trap at Ukiriguru was set up at the station towards the end of 1961 and forms a network of light traps scattered in East Africa to monitor and forecast S. exempta (Wlk.). It is a Robinson type of trap fitted with a 125-watt mercury vapour bulb (Plate 4) which operates daily from 6pm to 6am. The trap is adjacent to the main office buildings next to the Machatu field (Fig. 35), 180m away from the site of the pheromone trap. The catch was collected, sexed and recorded daily. Recent frequent power cut-offs have resulted in irregularity in the daily records, a problem which will not affect pheromone traps.

6.2.2 Pheromone traps at Ukiriguru

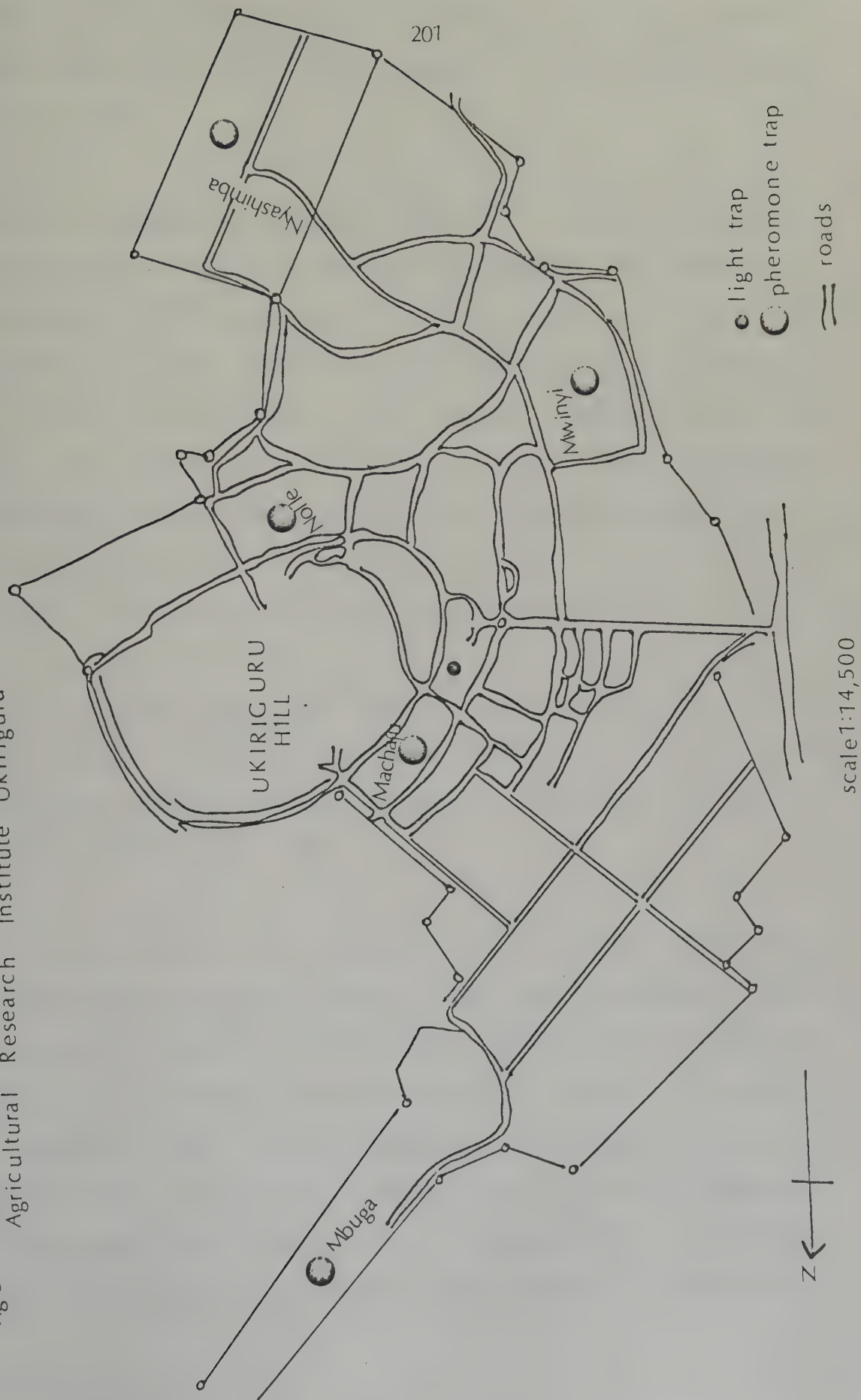
Research on H. armigera pheromone trapping began at Ukiriguru in January 1982. The pheromone capsules were provided by Dr. B.F.



Plate 4. The Robinson light trap at Ukiriguru.

Fig 35

Agricultural Research Institute Ukiriguru



Nesbitt of the Tropical Product Institute U.K. The pheromone constituted of 2mg Z11 - 16 Ald; 0.06mg Z9 - 16 Ald. (3%) and 2mg BHT as antioxidant.

6.2.2.1. Assessment of pheromone traps - The initial work involved the assessment of simple pheromone trap designs. When selecting the trap designs for testing, apart from being limited by the range of trap designs locally available, consideration was given to the cost of the trap and the amount of skill needed to construct and run the trap. Trap design availability and cost were the most limiting factors and thus only a few designs were evaluated between February and June 1982 (Fig. 36 and Plates 5a to c). Trap colour and placement height above crop canopy were also investigated.

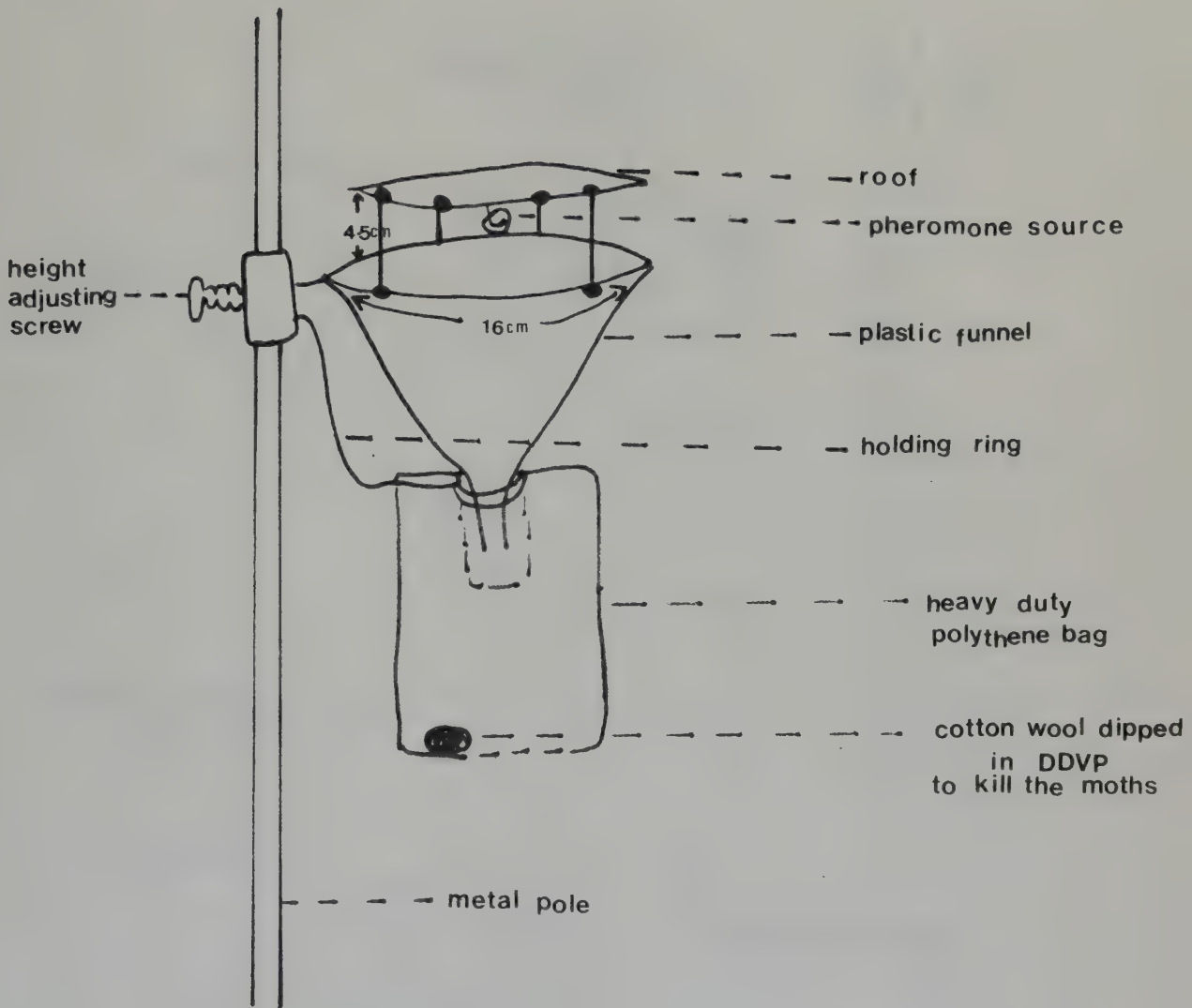
6.2.2.1.1. Trap design and colour - Trap design can have a considerable influence on the total catch and the value of the information collected (Marks, 1978; Cardé, 1979; Croft, 1979; Dix and Doolittle, 1984; Wilson, 1984).

Visual stimuli are an important aspect of insect orientation, and many flight interception trapping techniques use colour as a bait to increase the number of insects caught (Nyambo, 1980; Meyerdirk and Moreno, 1984; Meyerdirk and Oldfield, 1985). However, the response of insects to colour differs markedly from one group to another, and therefore there is the need to identify the best colour attractant for the insect being studied. Thus, Strickland (1961) reported that white water traps strongly attract several species of thrips which

Fig 36

Trap designs

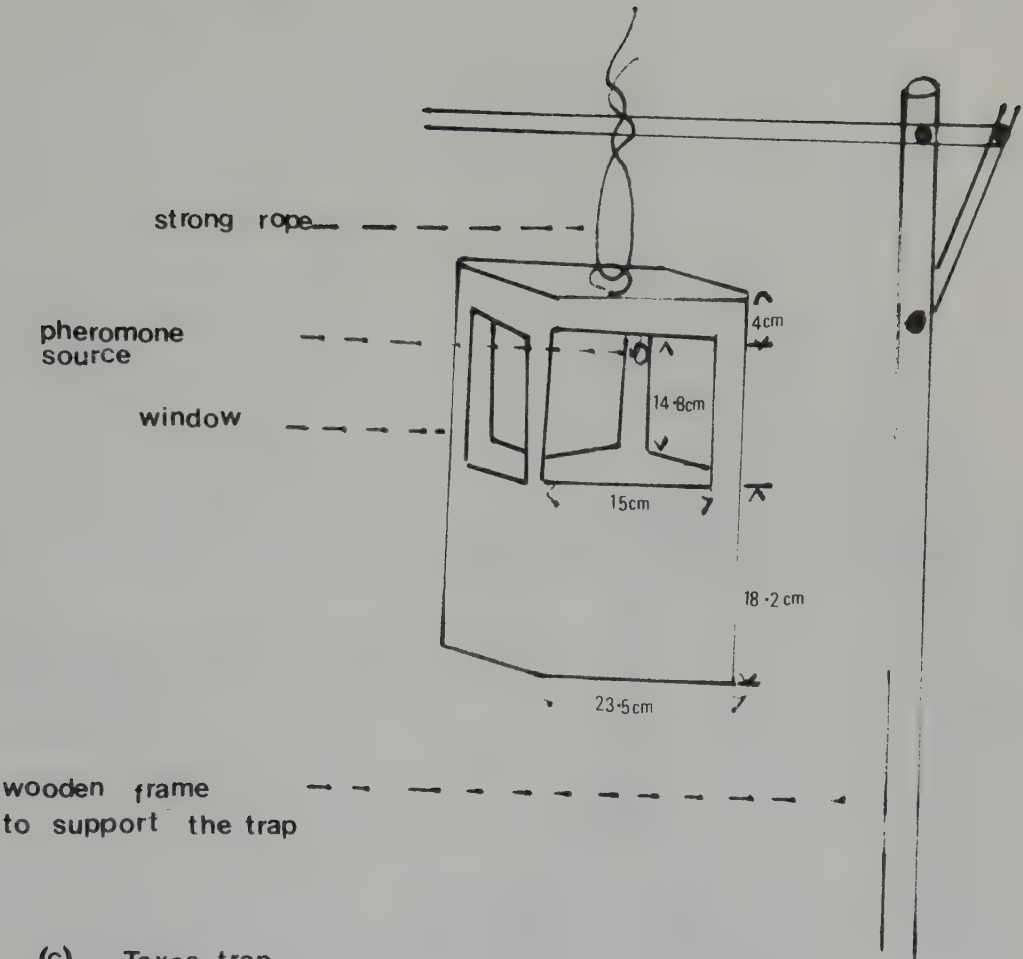
(a) EL-Dieb trap



(ex- ICRISAT funnel was 20.5cm at the widest part;
2.5cm at the narrowest end)

Figure 36 continued

(b) Mushi trap



(c) Texas trap

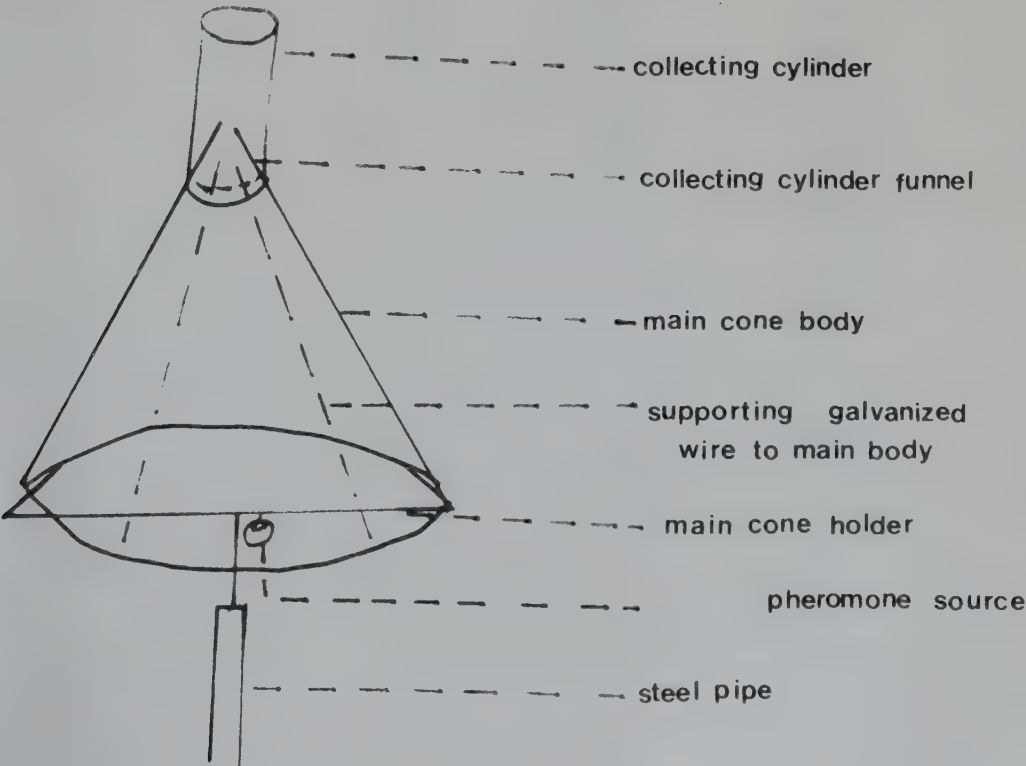


Figure 36 continued

(d) Ukiriguru trap

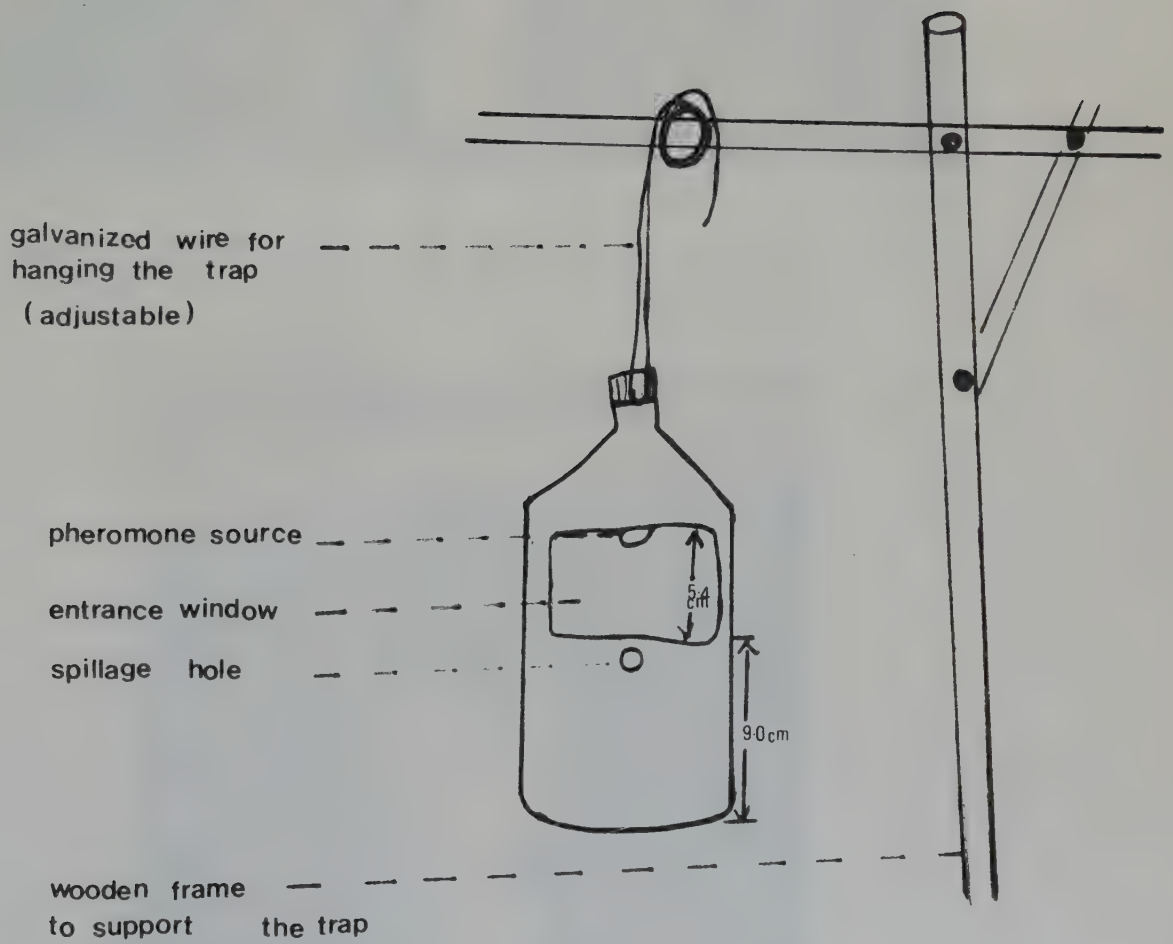




Plate 5a) EL-Dieb funnel trap set in a cotton field.



Plate 5b) ICRISAT funnel trap set in a cotton field.

feed mainly on flowering plants whereas many aphid species are strongly attracted to yellow coloured traps in contrast to the European chafer adults which prefer black and red coloured traps. Thus, colour of the trap may improve catches for any given trap design (Marks, 1978), and therefore it was necessary to assess the efficiency of different trap designs and colour in order to identify a suitable trap for use in Tanzania.

6.2.2.1.1.1 Material and methodology. - The following trap designs were assessed.

- a) Yellow plastic funnel, EL-Dieb trap, kindly provided by Dr. D. Campion of TDRI, U.K. (Fig. 36a and Plate 5a) (Critchley and EL-Deib, 1981).
- b) White plastic funnel, 'ICRISAT' trap. Similar design as (a) but only slightly larger (Fig. 36a, Plate 5b). The funnels were provided by Dr. W. Reed of ICRISAT where they were being used to monitor H. armigera.
- c) 'ICRISAT' funnel trap painted yellow.
- d) Yellow painted 20l. water tin (debe) 'Mushi' trap, with large windows cut on the sides. The trap is commonly used in Tanzania to monitor S. exempta (Wlk.) (Fig. 36b). Soapy water was used as the trapping medium.
- e) Wire mesh cone type, the Texas pheromone trap (Fig. 36c) which have been used successfully in the USA to monitor Heliothis spp. The design was provided by Prof. J.R. Phillips of the University of Arkansas USA.
- f) White plastic one-litre standard Micron ULVA bottle with two



Plate 5c) i. Ukiriguru pheromone trap in a cotton field.



- Plate 5c) ii. Ukiriguru pheromone trap - a close-up to show the main features of the trap.

large windows cut on the sides (Fig. 36d and Plate 5c). Soapy water was used as a trapping medium.

g) As (f) but the bottle was painted yellow.

The last two traps will be referred to as Ukiriguru trap design in the text.

The traps were put out on two sites at Ukiriguru research station viz: Machafu and Mbuga cotton fields (Fig. 35) to establish whether there were any site variations in the performance of the traps. Only the Ukiriguru trap design could be replicated because it was easy and cheap to make locally. The catch from each trap was recorded daily and the water traps topped up regularly to ensure there was adequate amount of water. In traps (a) to (c) a piece of cotton wool soaked in Dichlorvos 50% e.c. was put in the collecting bag to kill any moths caught. The cotton wool was replaced as soon as there was a sign of no kill. The Texas trap collected live moths. The pheromone capsules were renewed after 4 weeks of field use.

6.2.2.1.1.2. Results and discussions - The data from the two sites is summarised in Figure 37a and b, Table 22 and Appendix 6.

The mean weekly moth catch results at the Mbuga site (Fig. 37a) showed that overall, there were no significant differences between the trap designs or colours although the ICRISAT yellow trap caught more moths than the other traps (Table 22ai). However, Fig. 37a shows two peaks of moth flight. The first peak occurred from week 8 to 16 and the second and lower peak from week 17 to 25. The data was thus divided and analysed separately for the two peaks (Table 22 aii

Fig 37 *H. armigera* pheromone trap design and colour comparisons at Ukiriguru in 1982: Weekly total moth catch transformed to $\text{Log}(X + 10)$

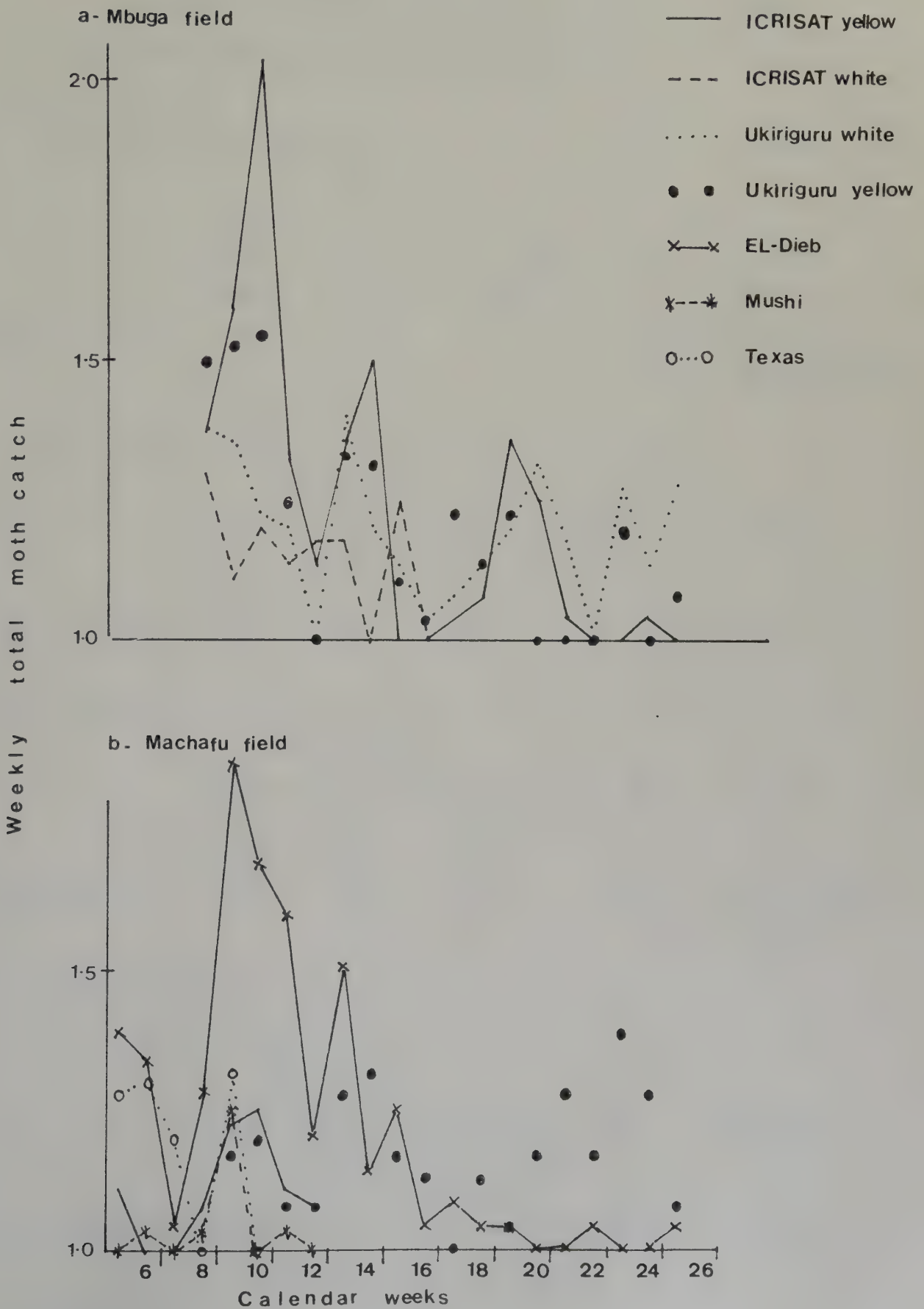


Table 22. Comparisons of H. armigera weekly total moth catches in different trap designs and colours at Ukiriguru in 1982:

Weekly moth catch transformed to $\text{Log}(X+10)$

a) Mbuga field site

i. Moths caught from week 8 to 25

	Trap designs			SE	P-value
	ICRISAT	Ukiriguru	Ukiriguru		
	Yellow	White	Yellow		
Mean catch/week	1.23	1.19	1.19	±0.032	
					Differences not significant at P = 0.05

ii. Moths caught from week 8 to 16

	Trap designs				SE	P-value
	ICRISAT	ICRISAT	Ukiriguru	Ukiriguru		
	Yellow	White	White	Yellow		
Mean catch/week	1.37	1.12	1.22	1.29	±0.052	≤0.05

iii. Moths caught from week 17 to 25

	Trap designs			SE	P-value
	ICRISAT	Ukiriguru	Ukiriguru		
	Yellow	White	Yellow		
Mean catch/week	1.09	1.16	1.09	±0.033	Differences not significant at $P = 0.05$

b) Machafu field site

i. Moths caught from week 5 to 8

	Trap designs				SE	P-value
	EL-Dieb	ICRISAT	Mushi	Texas		
		Yellow	trap	trap		
Mean catch/week	1.44	1.11	1.04	1.16	±0.046	≤0.001

Table 22 (Continued)

ii. Moths caught from week 9 to 12

	Trap designs					SE	P-value
	EL-Dieb	ICRISAT	Mushi	Texas	Ukiriguru		
		Yellow	trap	trap	Yellow		
Mean catch/week	1.59	1.17	1.07	1.12	1.13	±0.058	$P \leq 0.001$

iii. Moths caught from week 13 to 25 in the EL-Dieb and Ukiriguru traps

	Trap design		P-value
	EL-Dieb	Ukiriguru	
Mean catch/week	1.09	1.18	≤ 0.001
SE	± 0.142	± 0.115	

and iii, Appendix 6a). The trap differences between the number of moths caught in the first peak were significant at $P \leq 0.05$ (Table 22a_{ii}). During the first peak, the yellow coloured traps were equally sensitive and caught more moths than the white coloured traps. The 'ICRISAT' yellow painted funnel trap caught significantly, $P \leq 0.05$, more moths than the white funnel trap and the Ukiriguru white bottle trap. However, there were no significant differences between the different colours of the Ukiriguru traps (Table 22a_{ii}). In the second half of the trapping period, the moth population tended to decline and fewer moths were caught (Fig. 37a). However, although the Ukiriguru white trap caught more moths in comparison to the other trap designs and colours (Table 22a_{iii}) the differences were not significant. The yellow painted traps tended to be progressively less sensitive with field use possibly because the paint tended to change with time.

At Machafu field, the results (Fig. 37b) were grouped into three periods of trapping and analysed separately (Table 22b_i to iii and Appendix 6b). Between weeks 5 and 8 only four trap designs were assessed (Table 22b_i). Overall, the EL-Dieb trap was the most sensitive and caught significantly more moths, $P \leq 0.001$, compared to the other traps (Table 22b_i). The Texas and ICRISAT traps were second best and equally sensitive. The Mushi trap was the least sensitive and caught significantly less, $P < 0.05$, moths than the Texas trap (Table 22b_i and Appendix 6b). From weeks 9 to 12, five trap designs were assessed (Table 22b_{ii}). The results indicated that the funnel traps were more sensitive compared to the other trap

designs. The EL-Dieb trap was significantly more sensitive $P \leq 0.001$, than the other traps (Table 22bii), there being no significant differences between the other trap designs. However, the Ukiriguru trap caught more moths than the Mushi trap despite the fact that the two traps are of a similar design with differences in construction material. Differences in the reflective nature of the trap surfaces could partly explain the differences in catch because the nature and reflectivity of a trap surface as seen by the insect may be more important in optomotor reaction than subjective colours as seen by the human eye (Kennedy, et al, 1966; Affeldt, et al, 1983; Webb, et al, 1985). Thus, there is a need to investigate further and select the appropriate trap construction material and colour for the target insect.

In the third part of the experiment which covered weeks 13 to 25, only the EL-Dieb and the Ukiriguru traps were evaluated (Table 22biii, Appendix 6biii). Overall, the EL-Dieb trap became progressively less sensitive with field use (Fig. 37b) and caught significantly, $P < 0.001$, fewer moths than the Ukiriguru trap (Table 22biii). The same funnels were used successfully in Egypt to trap Spodoptera littoralis (McVeigh, Paton and Hall, 1979) and has been adopted as a standard trap for S. littoralis in Egypt (Critchley and EL-Dieb, 1981). The funnels have to be dusted with French chalk or Talcum powder (D. Champion, 1981; personal communication) on the inside to make it difficult for the moths to cling onto the sides but this was not done in the study. However, McVeigh, et al (1979) reported an increase in moth numbers with use of undusted funnel

traps and suggested that the accumulation of dust and scales in the funnel from captured moths could have led to an increased catch. The decline in efficiency observed in the study could be due to a relatively faster decline of the pheromone formulation on the trap as a result of poor protection from the direct effects of sunlight (D. Campion, 1986, personal communication).

Despite the fact that the EL-Dieb trap caught more moths than any of the other traps it had several limitations. First its efficiency declined with time in the field (Fig. 37b). Secondly, large funnels with similar colour and diameter to the ones used in this experiment were not locally available. Funnels with a smaller diameter of 10-12cm were found to catch less moths in Egypt (McVeigh, et al, 1979). Third, the construction of the complete trap framework was costly as it required welding of the framework, metal screws, supporting metal rods or steel pipes and the use of heavy duty polythene bags, which were not readily available.

The Texas pheromone trap was particularly interesting because apart from monitoring the activity of the adult population, it can also be used for mark-release studies as it catches live moths. Of course the funnel traps can also be used to catch live moths by omitting the killing agent in the collecting bag. However, the wire mesh is very costly and not easily available locally. Secondly, the trap was susceptible to vandalism, as the wire mesh has high demand, even at the station where there is high security. Third, it was generally less robust and more expensive than the other traps.

The Mushi trap had the lowest catch and was therefore not suitable for H. armigera trapping. In addition, the trap needs not less than 4L. of water at full capacity which makes it unsuitable for use in dry areas. Also, the tin rusts easily thus requiring regular replacement. Painting has not been particularly good in extending the longevity of the trap.

The Ukiriguru traps were most satisfactory. Although the traps caught less moths compared to the EL-Dieb trap, the most important observation is that the traps were capable of showing the peaks of moth flight and were more sensitive during a period of low moth activity (Fig. 37b). Another advantage of the Ukiriguru traps is that they are very light and simple to make and instal in the field. The supporting structure (Fig. 36d and Plate 5c) is also very simple. The traps also require only 500 mls of water at full capacity and therefore are probably ideal for areas where water is in short supply.

Following these observations it was decided to evaluate the Ukiriguru trap in more detail. Traps were therefore put on several sites at the station to monitor H. armigera activity on different fields within the Institute beginning from April to the end of July 1982, and to assess some of the limitations of the design. The traps were set up in pairs (white vs. yellow) at Mwinyi, Nyashimba, Nolle and Mbuga cotton fields (Fig. 35). The weekly data is summarized in Appendix 7.

Table 23. Summary of H. armigera total moth caught in the Ukiriguru white and yellow painted pheromone traps: Weekly collections from individual fields (Appendix 6) pooled to assess trap colour differences. Data from Machafu field site not included

Calendar week	White trap	Yellow trap	
13	78	117	
14	86	72	
15	13	36	
16	13	20	
17	29	21	
18	20	29	
19	37	24	
20	44	22	
21	17	19	
22	9	31	
23	24	91	
24	28	76	
25	53	77	
26	48	70	
27	12	6	
28	6	19	
29	7	8	
Total	524	758	
Mean catch/week	30.8	44.6	differences not statistically significant
SE	± 24.08	± 32.04	

The data in Appendix 7 is further summarized in Table 23 in order to make an overall assessment of the differences in the number of moths caught in the white and yellow painted traps. Overall, the trap catches followed a similar trend except that the yellow painted trap was more sensitive although not significantly better than the white trap (Table 23 and Appendix 8). Due to unavailability of a high quality yellow paint that will remain stable in the open air without being bleached and peeling from the bottle, it was decided to opt for the white bottle trap for further research work.

Despite the fact that the Ukiriguru trap gave promising results and was finally used over a number of sites in Tanzania, the following problems were observed:

- a) The plastic tends to harden and crack easily after being out in the field for several months and therefore needs replacement every 5 to 6 months.
- b) The supporting wooden pole is liable to termite damage in areas where termites are a problem. If the pole is lightly brushed with a weak aldrin e.c. solution about 1/2 m above ground level, the life of the pole is prolonged.
- c) In dry seasons, the water requires topping up daily.
- d) The catch has to be recorded daily, preferably early in the morning to avoid loss of moths due to predators.

To obtain a guideline on approximate trap density, a comparison of moth catches between sites at the Institute was done (Fig. 38). The weekly moth catch data (Appendix 7) in the white and yellow

Fig 38 Comparison of *H. armigera* adult moth activity at different sites within Ukiriguru Research Station using pheromone traps: April to July 1982.

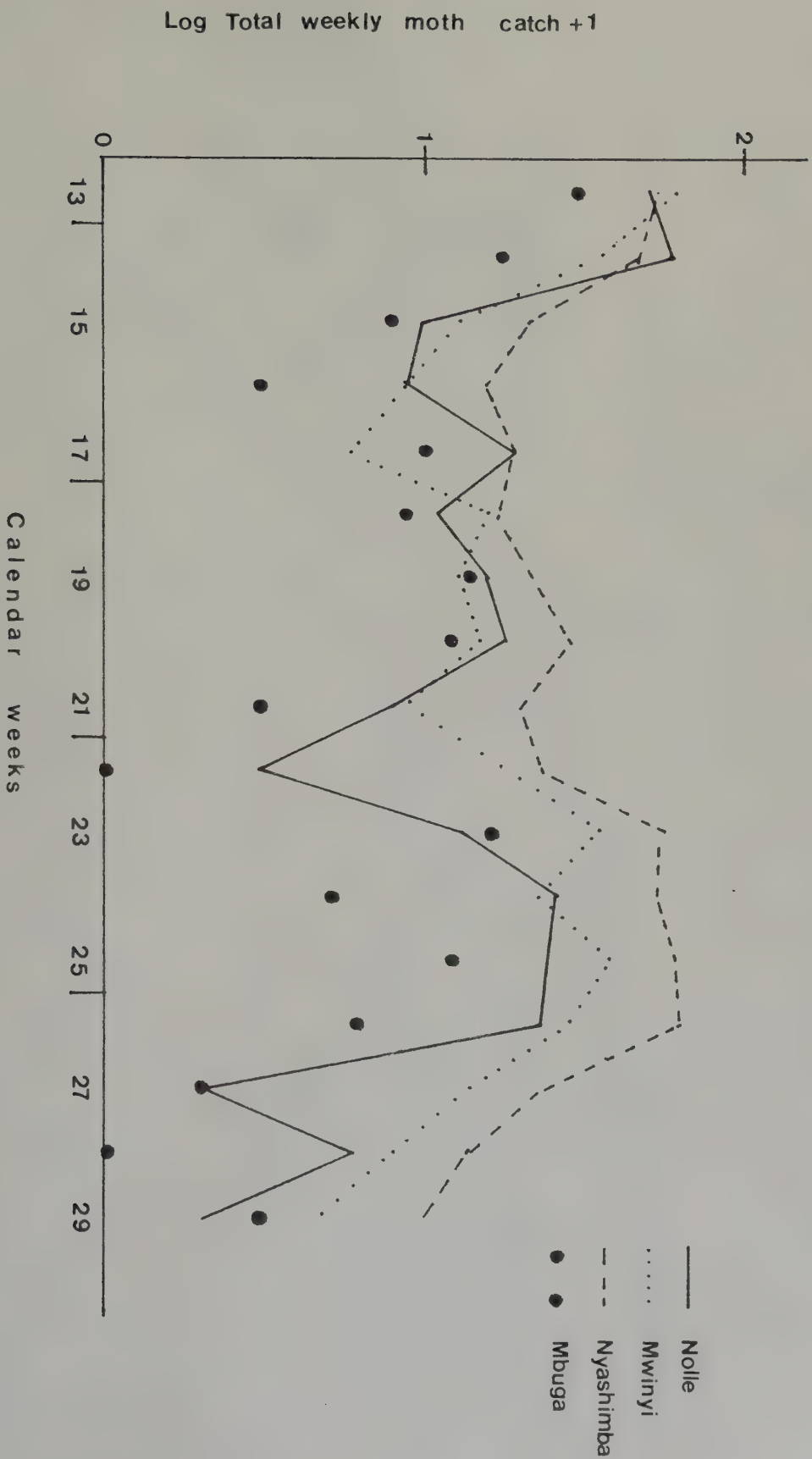


Fig 39

Mabuki Cotton Seed Multiplication Farm

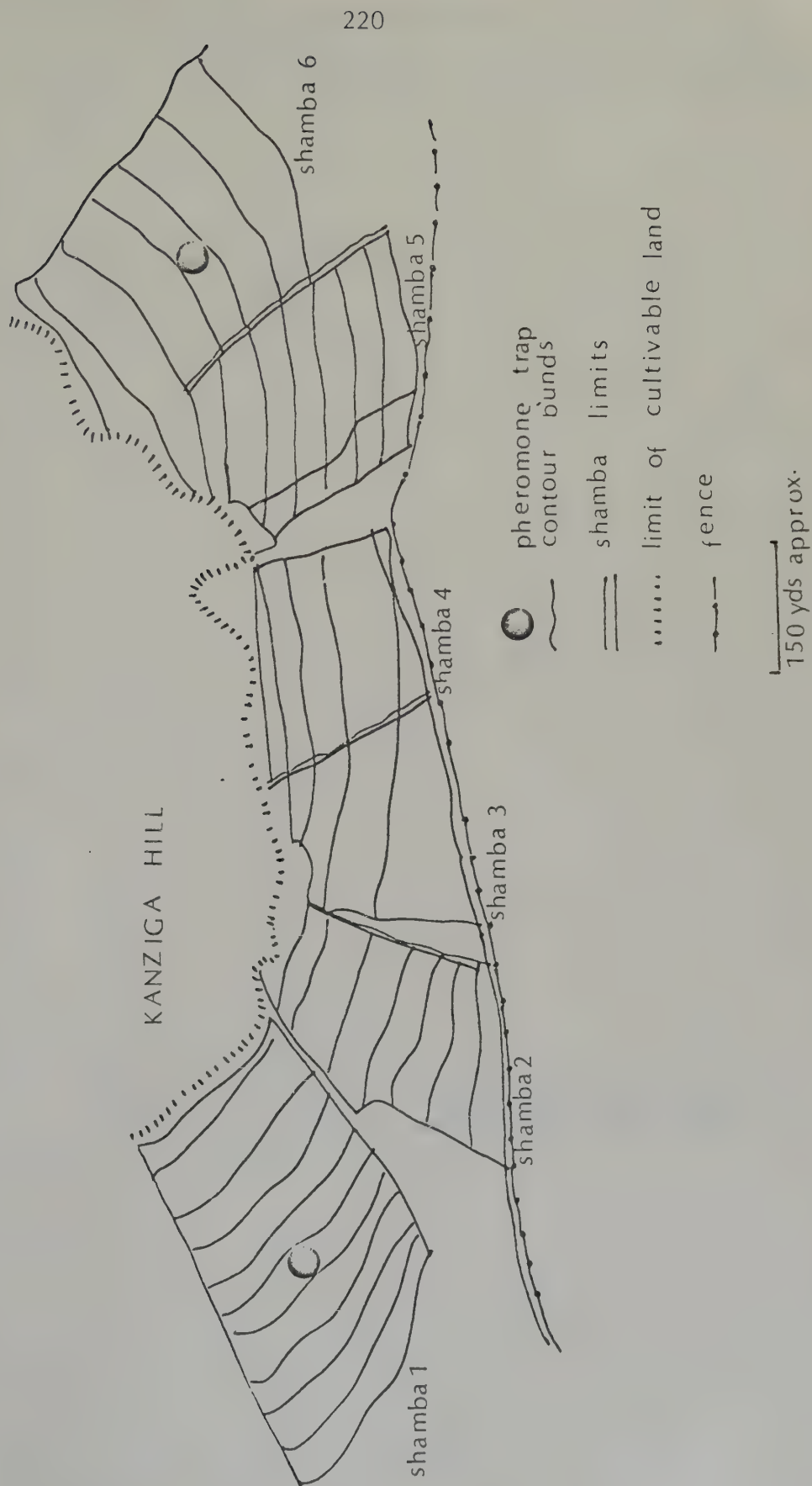


Table 24. Weekly total H. armigera moth caught in pheromone traps
at Shamba 1 and 6 Mabuki seed cotton multiplication farm
in 1982.

Calendar Week	Shamba No. 1	Shamba No. 6
7		64
8		64
9	79	20
10	117	22
11	69	33
12	50	0
13	38	2
14	168	3
15	15	2
16	8	66
17	6	66
18	9	31
19	67	31
20	74	26
21	34	39
22	38	58
23	28	26
24	37	37
25	36	57
26	40	43
27	13	4
28	17	23
29	11	13
30	4	2
Total	958	604
Mean	43.5	27.4
SE	±40.09	± 21.23

Differences statistically
significant at $P < 0.05$

painted traps at each site were pooled to give weekly site total in order to make between site comparisons. The results showed that there were significant variations in the level of H. armigera moth activity between different fields at the Institute (Fig. 38 and Appendix 9). The Institute occupies 440ha and although there was a general trend of moth activity, the trap at Nyashimba caught significantly more, $P < 0.001$, moths than the traps at the other sites. The trap at Mbuga caught significantly fewer moths, $P < 0.001$, compared to the other sites. Significant site variations in the number of moths caught were also recorded at Mabuki cotton seed multiplication farm (Fig. 39). The trap at Shamba No. 1 caught significantly, $P < 0.05$, more moths than the trap at Shamba No. 6 (Table 24 and Appendix 10). Pheromone traps in exposed positions tends to catch more moths than traps in sheltered positions apparently because in exposed positions scent trails are unimpeded (Campion, 1976). All the trap sites in this study were located in relatively exposed areas and therefore factors other than topographical could influence the catch. At Ukiriguru Institute for example, the H. armigera pest pressure on cotton, maize and sorghum is often higher at the Nyashimba fields than in most other fields in the station. Therefore, there is the need to investigate further the factors influencing catch at any one particular site in order to be able to make better use of pheromone trap data.

Trap density was not investigated in the present study but the approximate trap spacings and trap areas are shown in Table 25 and Fig. 40. The trap at the Mbuga site was very isolated and its

Table 25. Assessment of the performance of the Ukiriguru pheromone trap design at different sites at Ukiriguru in 1982.

a) Trap spacings and approximate trapping area at Ukiriguru

i. Trapping area per individual field

Field site	Area under cotton, maize and sorghum
Nyashimba	37.5 ha
Mwinyi	22.3 ha
Nolle	25.8 ha
Machafu	10.6 ha
Mbuga	10.0 ha

b) Trap spacings and approximate trapping area at Mabuki seed cotton multiplication farm.

i. Trapping area per individual field

Shamba No. 1 approximately	15.4 ha of cotton
Shamba No. 6 approximately	15.4 ha of cotton

The spacing between the two fields was approximately 1000m.



Fig. 40. Approximate trap spacing between fields at Ukiriguru Institute
- Sketch diagram

performance could not have been influenced by any of the other traps. However, despite significant site variations in the level of H. armigera activity at the station it is important to note that all the traps showed a similar trend of activity. Thus, to monitor the presence of the pest one trap in an area can be relied upon. However, to plan control strategies, the need to investigate optimum trap density is inevitable. In the USA, the Texas pheromone trap is used at one trap per 20ha of cotton to give reliable indices of Heliothis population occurrence (Prof. J.R. Phillips, University of Arkansas, USA, 1981; personal comm.).

6.2.2.2 Trap placement height - Trap height and position relative to nearby foliage and visual cues can affect catch considerably. In many situations where pheromone traps have been used to monitor the activity of a target insect pest, the catches have been improved by placing the trap at a suitable height above plant canopy (Sharma, et al, 1971; Hendricks and Leal, 1973; Marks, 1978; Dix et al, 1979; Cardé, 1979; Rothschild, et al, 1981; Meyerdirk and Oldfield, 1985). When pheromone trapping began at Ukiriguru it was suggested that traps be maintained above the crop level (Dr. D. -Campion, TDRI, UK, 1981; personal communication). However, since no height specifications were given, it was decided to assess the effective optimum height above crop level in order to improve the catch size and thus collect adequate information.

This experiment was set up at a time when the cotton plants had attained optimum height. The traps were examined daily and the catch

recorded. The placement heights and the daily moth catch records are shown in Table 26.

Overall, moth activity during the experimental period was very low (Table 26) and therefore could not be analysed statistically. Catch increased with increasing height above the crop level. Thus, the trap at 60cm above the crop level, the highest, caught 54% more moths than the trap 30cm above the canopy whereas the trap at 30cms caught 50% more moths than either the trap just at crop level and 10cm above the vegetation. The trap below the vegetation caught the least number of moths.

The experiment was repeated in 1983 and was set up when cotton was flowering and still growing vigorously. The placement heights and daily moth catch are shown in Table 27. The data in Table 27 was analysed using analysis of variance (Appendix 11a), and although the trap placed 80cm above the plant canopy caught more moths, the differences between placement height were not significant. Due to many days with zero or few catches, it was decided to do partial analysis of catches when moth catch per night was 5 or more to see if there were differences in placement height on such occasions. Although the trap at 80cm above crop canopy caught more moths the differences between placement heights were not significant (Appendix 11b). However, 80cm above the crop level appeared to be the optimum height above which catch began to decline. Other workers (Dix, et al, 1979; Sharma, et al, 1971) observed a decline in moth catch above the optimum placement height.

Table 26. H. armigera pheromone trap placement height experimental results at Ukiriguru in 1982: The traps were placed in a cotton field at boll maturity.

The experimental heights were as follows:

- A - 10cm below crop canopy
- B - 0cm above crop canopy (the trap touched the crop)
- C - 10cm above crop canopy
- D - 30cm above crop canopy
- E - 60cm above crop canopy

The average plant height when the experiment was done was 91.2cm.

Moth catches from 15th May to 15th June 1982 per night					
Date	Trap height below (-) or above (+) crop canopy				
	-10cm	0cm	+10cm	+30cm	+60cm
15 May	0	1	0	1	0
16	1	0	1	0	1
17	0	0	0	0	0
18	0	0	0	0	2
19	0	0	0	0	2
20	0	0	0	0	0
21	0	1	0	1	0
22	1	0	1	0	0
23	0	0	0	0	0
24	0	0	0	0	0
25	0	0	0	0	0
26	0	1	0	0	0
27	0	0	0	0	1
28	0	0	0	0	0
29	0	0	0	0	1
30	0	0	0	0	0
31	0	0	0	0	0
1 June	0	0	0	0	0
2	0	1	0	0	0
3	1	0	3	0	0
4	0	1	0	0	1
5	0	0	0	0	2
6	1	0	0	1	0
7	0	0	0	0	1
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	1	5
11	0	0	1	2	4
12	0	0	0	1	2
13	0	1	0	0	1
14	0	0	0	3	3
15	0	0	0	0	0
Total	4	6	6	12	26
Mean catch per night	0.1	0.2	0.2	0.4	0.8

Table 27. *H. armigera* pheromone trap placement height experimental results at Ukiriguru in 1983.

1983: The experimental heights were as follows

- A - 30cm above crop canopy
- B - 60cm above crop canopy
- C - 80cm above crop canopy
- D - 90cm above crop canopy
- E - 100cm above crop canopy

a) The traps were placed in the cotton field at flowering and the heights were adjusted weekly to match the plant growth height.

The experiment run throughout the month of March.

Results of moth catches per night

Date	Trap height above crop canopy				
	30cm	60cm	80cm	90cm	100cm
1	0	1	2	0	2
2	0	1	2	2	3
3	2	1	1	0	4
4	0	1	1	1	0
5	2	0	3	3	2
6	1	0	4	1	0
7	0	0	1	0	1
8	8	4	6	12	4
9	0	2	0	0	3
10	1	0	1	1	0
11	0	0	3	1	1
12	4	3	4	5	2
13	18	6	8	7	4
14	2	2	3	0	2
15	0	1	2	0	0
16	0	5	2	3	0
17	0	1	0	2	0
18	0	0	2	0	0
19	1	1	1	0	1
20	0	0	0	1	0
21	0	3	0	0	2
22	1	1	0	0	0
23	2	0	2	0	0
24	0	0	0	0	0
25	0	0	0	1	0
26	0	0	0	0	0
27	0	0	0	0	1
28	0	0	0	1	0
29	0	0	0	1	0
30	0	0	0	0	0
31	0	1	1	0	0
Total	42	34	49	42	32
Mean	1.35	1.09	1.58	1.35	1.03

± 0.268
Differences

not significant at $P = 0.05$

Table 28. H. armigera pheromone trap placement height experiment in a chickpea field: The experiment was set up just after germination and the traps were adjusted weekly to match plant height growth.

The experimental heights were as follows:-

- A - the trap touched plant canopy (0cm)
- B - 25cm above plant canopy
- C - 75cm above plant canopy
- D - 125cm above plant canopy

Moths caught 4th June to 4th July 1982.

Date	Trap height above plant canopy			
	0cm	25cm	75cm	125cm
4 June	0	0	0	0
5	1	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	2	1	0
9	0	1	0	0
10	0	3	1	4
11	1	1	0	1
12	1	2	0	0
13	1	3	1	1
14	0	6	1	1
15	0	3	0	0
16	0	1	0	0
17	0	0	1	0
18	2	1	0	0
19	2	0	0	0
20	0	0	1	0
21	0	0	0	0
22	1	1	2	1
23	0	0	0	0
24	3	2	3	0
25	0	2	0	0
26	0	0	0	1
27	4	2	0	0
28	0	2	0	0
29	0	2	0	0
30	1	4	0	0
1 July	1	1	1	0
2	0	1	0	1
3	0	0	1	0
4	0	0	1	0
Total	18	40	14	10
Mean	0.58	1.29	0.45	0.32

±0.171 Differences statistically significant at $P \leq 0.001$

A similar experiment was repeated in a chickpea field. Chickpea, unlike any other H. armigera host plants, can be infested by the pest at any stage even soon after germination. This crop provided an opportunity to compare trap placement height in a crop different from cotton.

The traps were placed in the field as soon as germination was complete and continued for 31 days. The placement heights and daily catches are shown in Table 28. Overall, moth activity was very low throughout the experimental period. However, the trap placed 25cm above the plant height caught significantly, $P \leq 0.001$, more moths than any of the other traps (Table 28 and Appendix 12). However, there were no significant differences in the number of moths caught between the rest of the placement heights. The trap 25cm above plant level caught 55% more moths than the trap maintained at the same level as the plant height, and 65% more moths than the trap 75cm above the plants. The trap at 125cm above plant canopy caught the least number of moths. The optimum placement height above the crop canopy in chickpeas was thus 25cm.

Thus, each crop or plant situation is likely to have an optimum placement height beyond which catch size will decline. In cotton, the traps should be maintained above the canopy level, preferably not above 80cm to maximize catch.

6.3 Comparison of pheromone and light trap moth catches at Ukiriguru: 1982, 1984 and 1985

The objective of the study was to compare the efficiency of the

pheromone trap catches relative to the light trap with the objective to obtain a better understanding of the pheromone trap catches.

A number of variables affect the possibility of a male being captured in a pheromone trap and these include trap design, meteorological factors and moth behaviour including competition effect between the trap and the wild females or trap-trap and the physiological status of the moth population (Cardé, 1979; Croft, 1979). Also, pheromone traps catch only sexually mature males whereas a light trap will catch moths of different ages and physiological status (Hartstack, 1979; Rose and Khasimmudin, 1979; Rose, 1979), and this makes data interpretation complex. Work done elsewhere to compare the catches in pheromone and light traps have indicated that often, more male moths are caught in the pheromone trap when females have been fertilized and have stopped releasing pheromone (Hendricks et al, 1973; Roach, 1975; Glen and Philip, 1982). Where both types of traps have been used, more moths (males and females) are frequently caught in the light than in the pheromone trap (Roach, 1975; Rose and Khasimmudin, 1979). Thus, the period when pheromone traps catch more moths than the light trap is important as this could be an indication of female egg oviposition, and therefore both types of traps may be necessary in monitoring and forecasting the pest population.

Data from the light trap and the pheromone trap at Machafu field were used in these studies. Due to power failure from the end of September 1982 to the end of 1983, only the data in 1982, 1984 and

1985 is summarized in Figures 41 to 43.

Overall, the pheromone trap catches followed a similar trend to the light trap in monitoring the general activity of the moth population (Figure 41a to c). Generally, H. armigera moths were caught throughout the year with an extended peak between February and June. This main peak was separated from the small peak which was often recorded between December and February by the dry season, July to November, when moth catches were generally low (Fig. 41a to c). However, the pheromone trap was more sensitive at low pest population levels, in particular between August and November 1984 (Fig. 41b). Moth catches in the pheromone trap were often higher only when both the number of females and males caught in the light trap were low and/or at a decline, in particular between January and June (Fig. 41a to c). Overall, the light trap caught a proportionately larger H. armigera moth population than the pheromone trap, especially during the main peak. Similar work done elsewhere (Hendricks, et al, 1973; Roach, 1975; Hartstack, et al, 1978; Hendricks and Hartstack, 1978) reported a similar trend of results.

The ratio of males to the number of females caught (sex - ratio) can give an estimate of the proportion of the wild female population which is sexually mature and mated and this can be used to predict the likely level of infestation. Thus, the trap data was analysed to establish the relationship between the ratio of males caught in the pheromone and light traps to the number of females caught in the light trap (Fig. 42i to iii and 43i to iii). Comparison of the

Fig 41 Comparison of pheromone male moths and light trap male and female H. armigera moth catches per week at Ukiriguru.

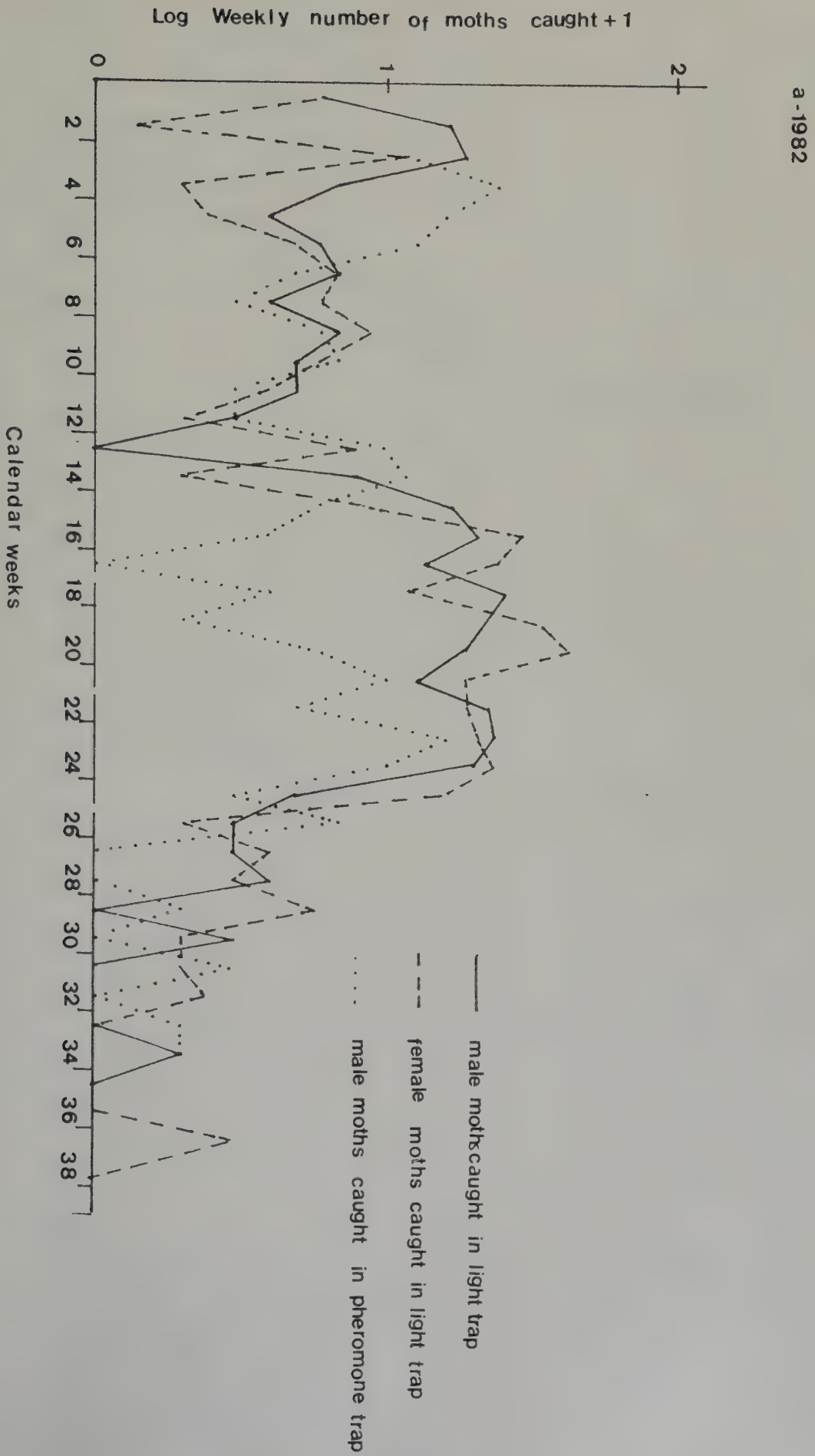


Figure 41 continued

b- 1984

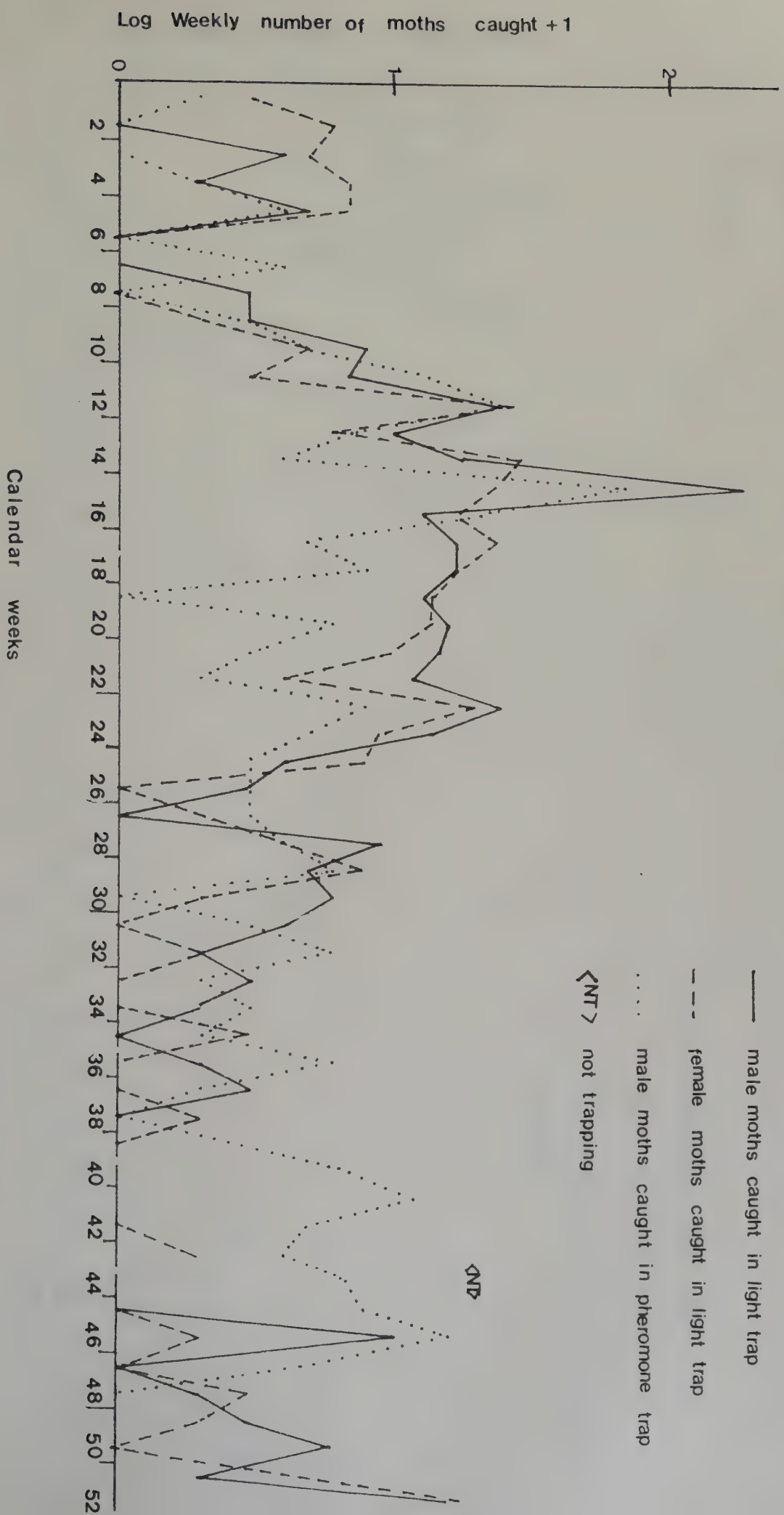


Figure 41 continued

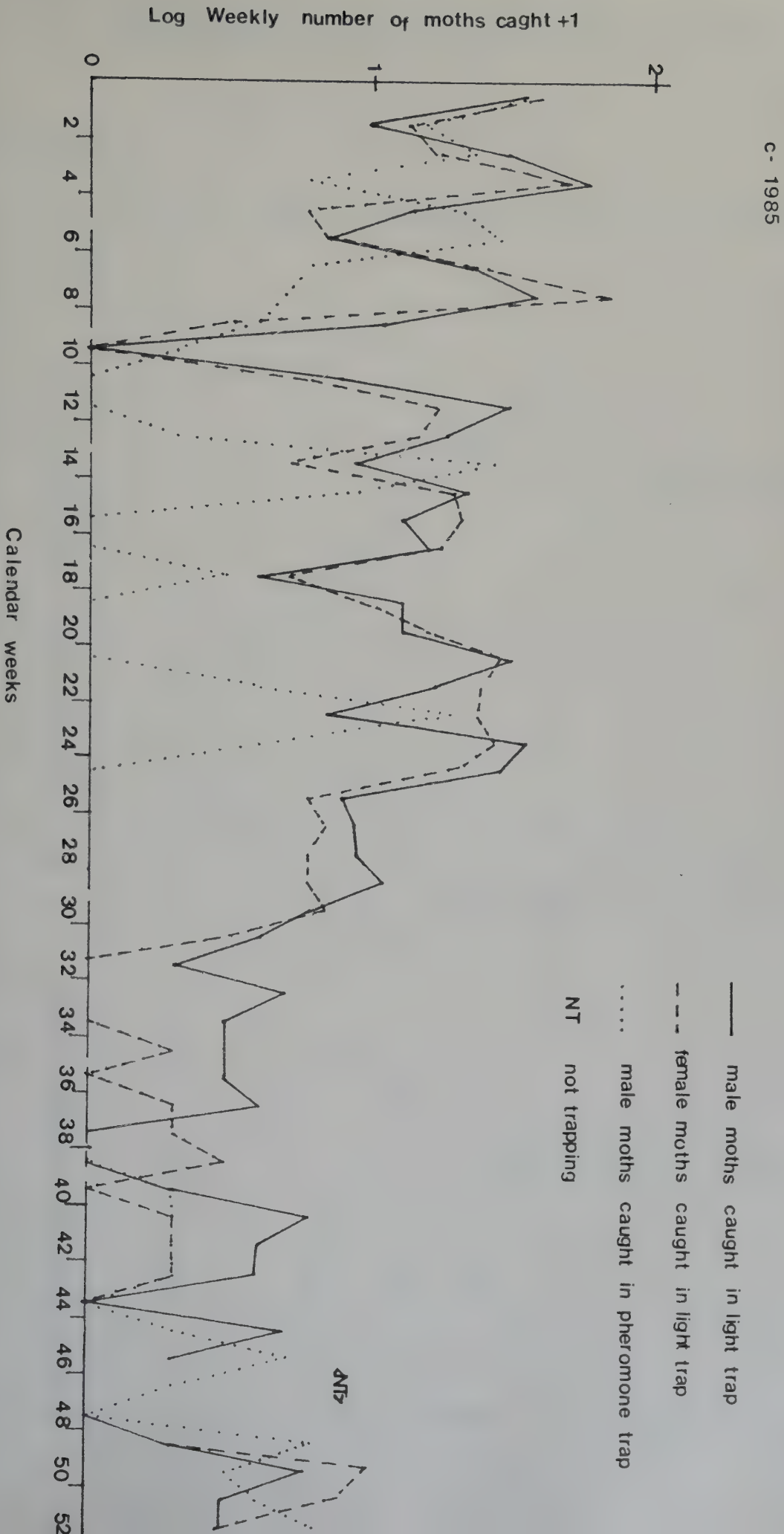
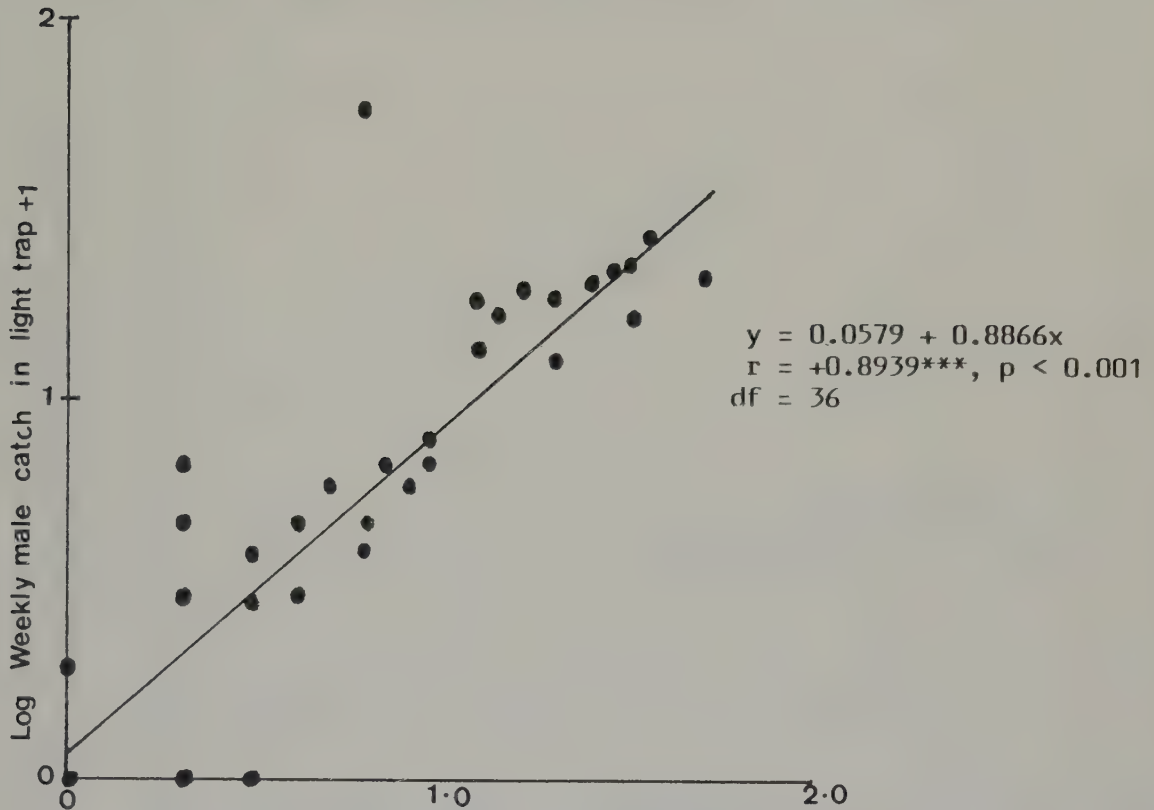


Fig 42 The relationship between the number of H. armigera moth catches in the pheromone and light traps at Ukiriguru.

i-1982

a- Adult males caught vs adult females caught in the light trap.



b- Adult males caught in the pheromone trap vs adult females caught in the light trap.

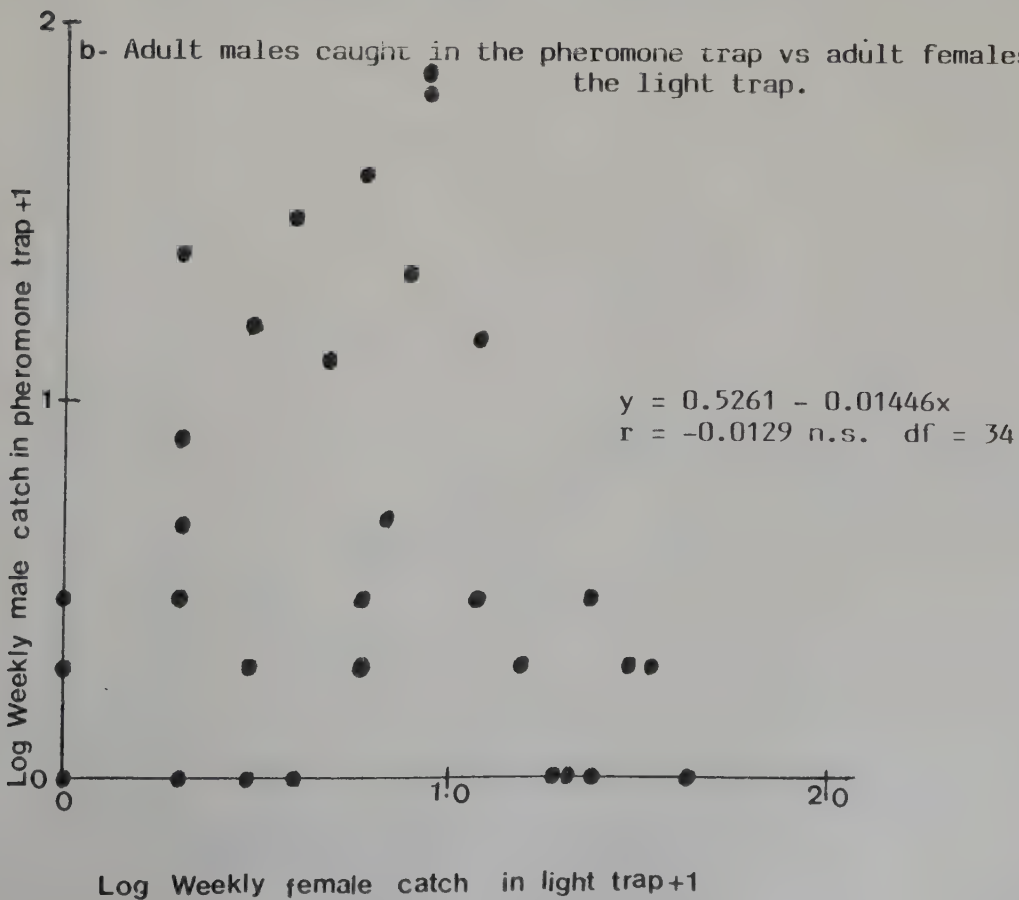
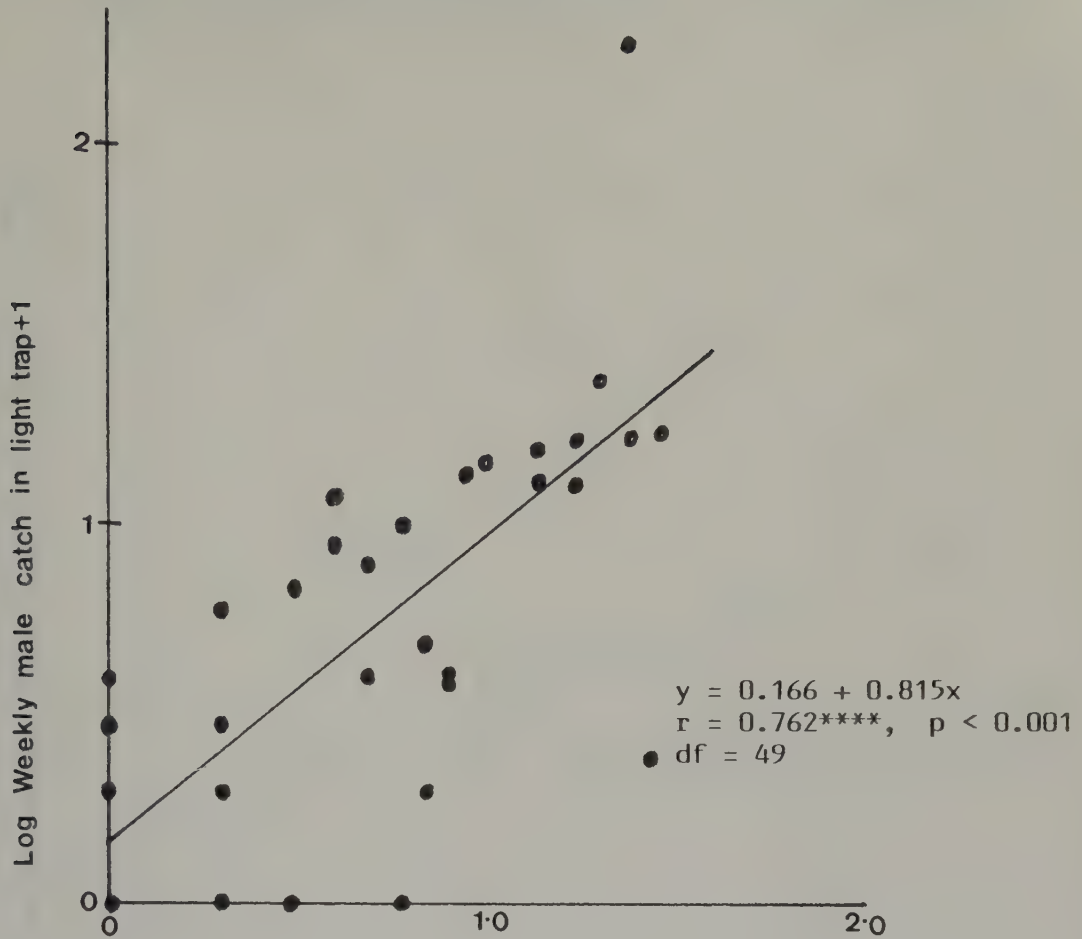


Figure 42 continued —ii- 1984

a- Adult males caught vs adult females caught in the light trap.



b- Adult males caught in the pheromone trap vs adult females caught in the light trap.

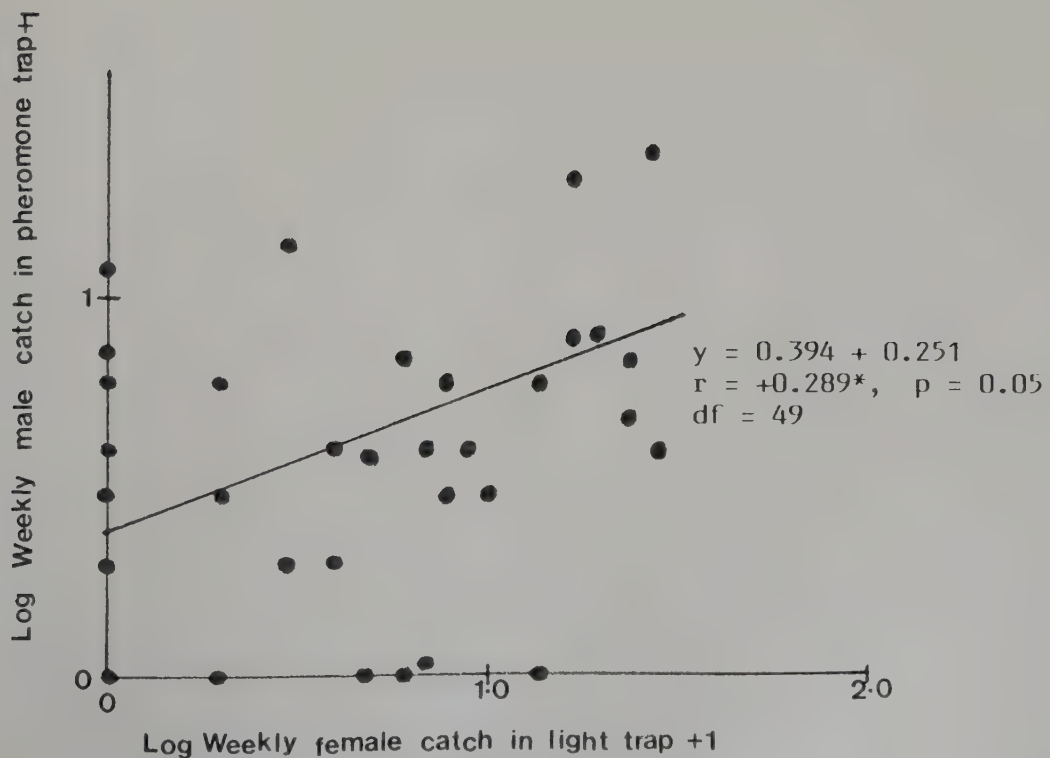


Figure 42 continued —1984-ii

- c- The relationship between the number of male moths caught in the light and pheromone traps.

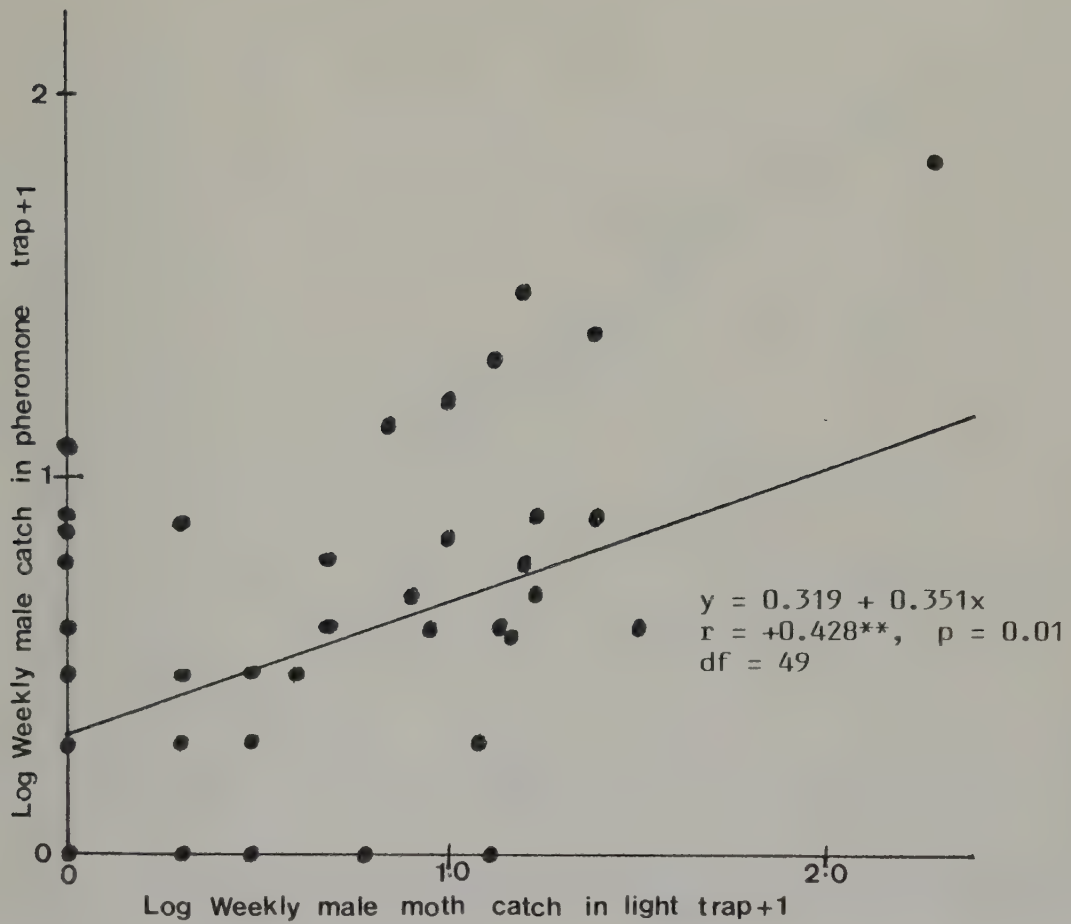
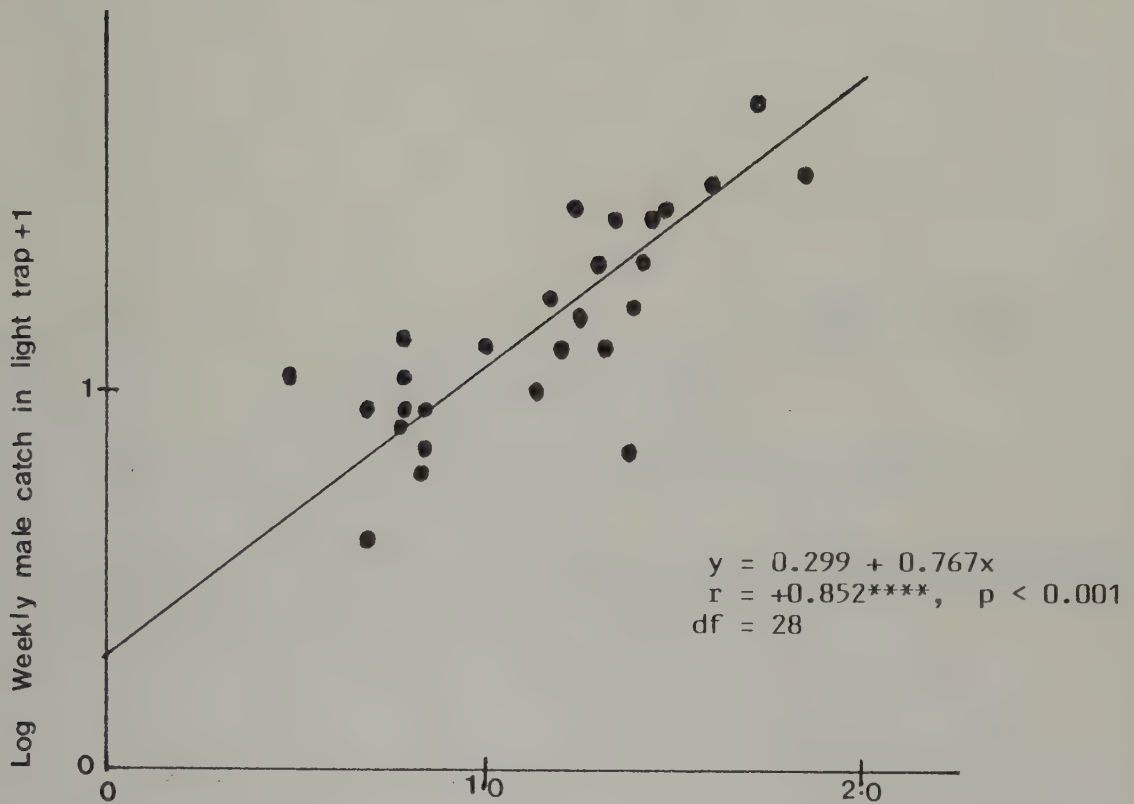


Figure 42 continued — iii - 1985

a- Adult males caught vs adult females caught in the light trap.



b- Adult males caught in the pheromone trap vs adult females caught in the light trap.

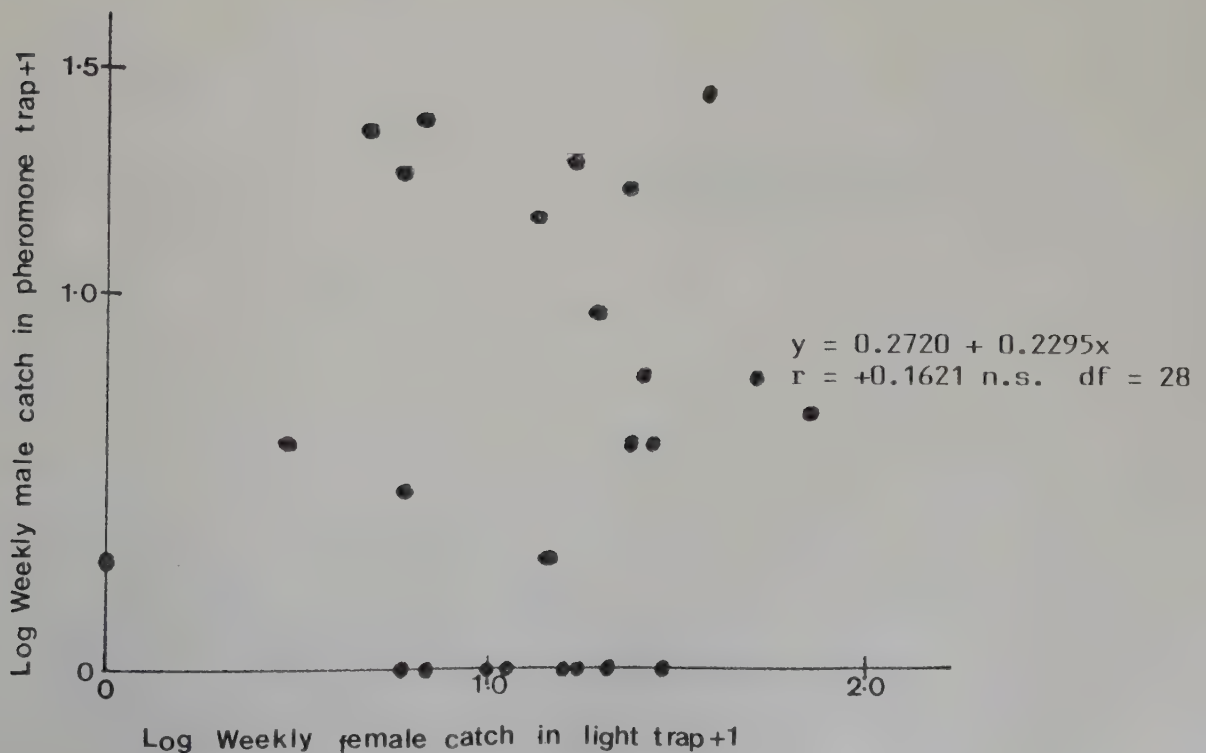
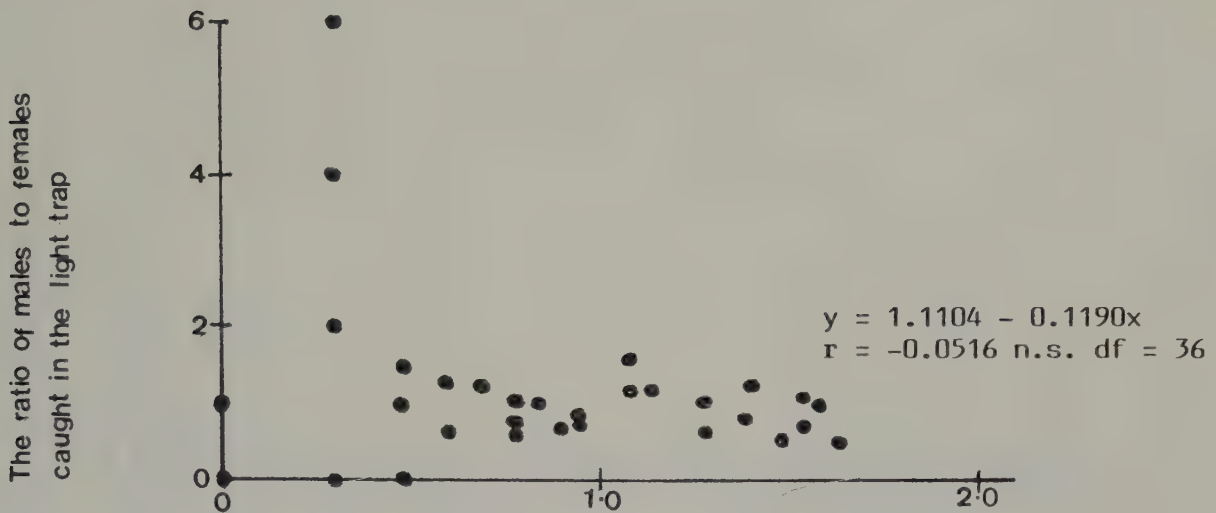


Fig 43 The relationship between the ratio of males to females caught in the light and pheromone traps.

i- 1982

- a- The ratio of males caught in the light trap plotted against the number of females caught in the light trap.



- b- The ratio of males caught in the pheromone trap plotted against the number of females caught in the light trap

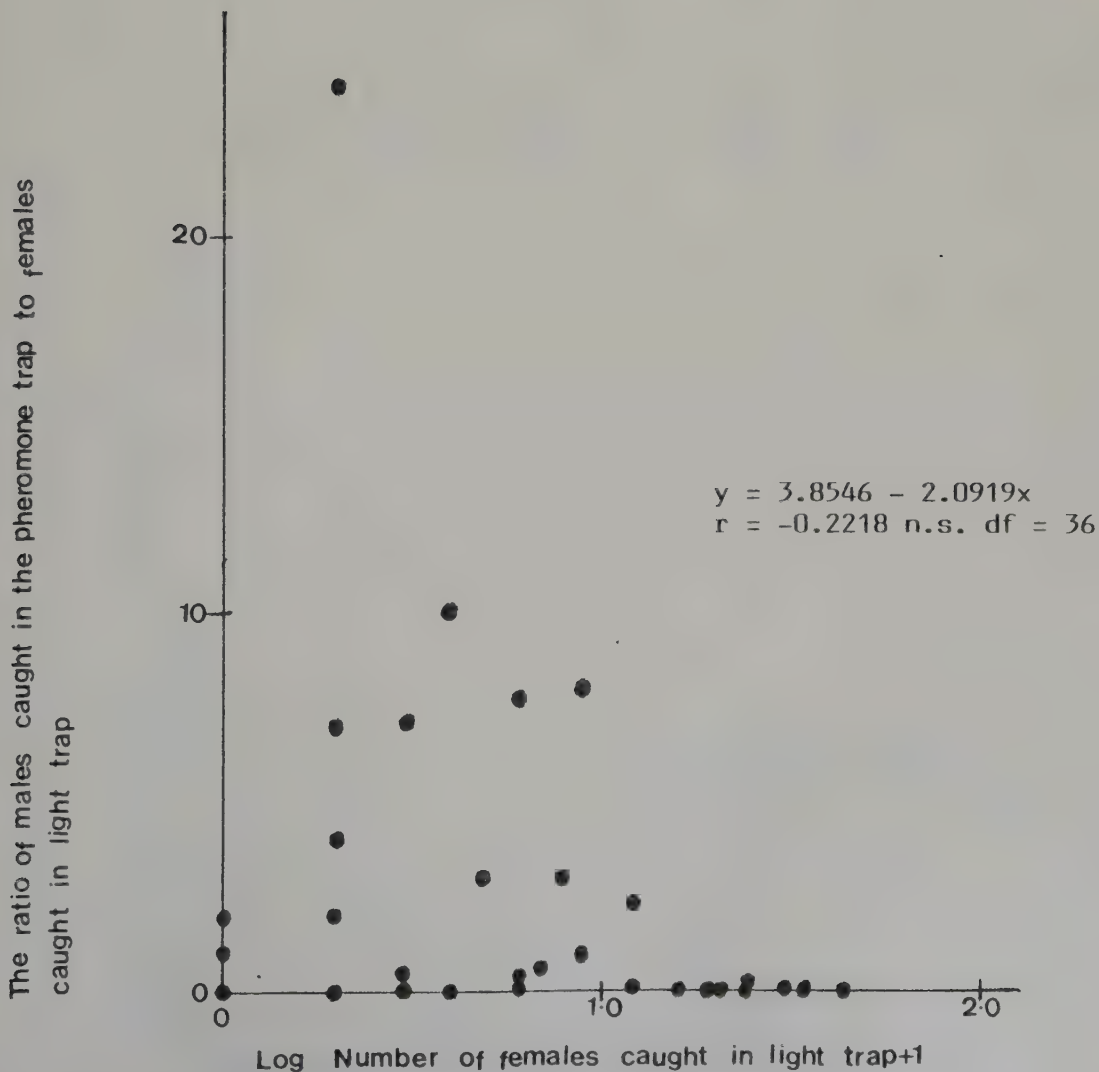
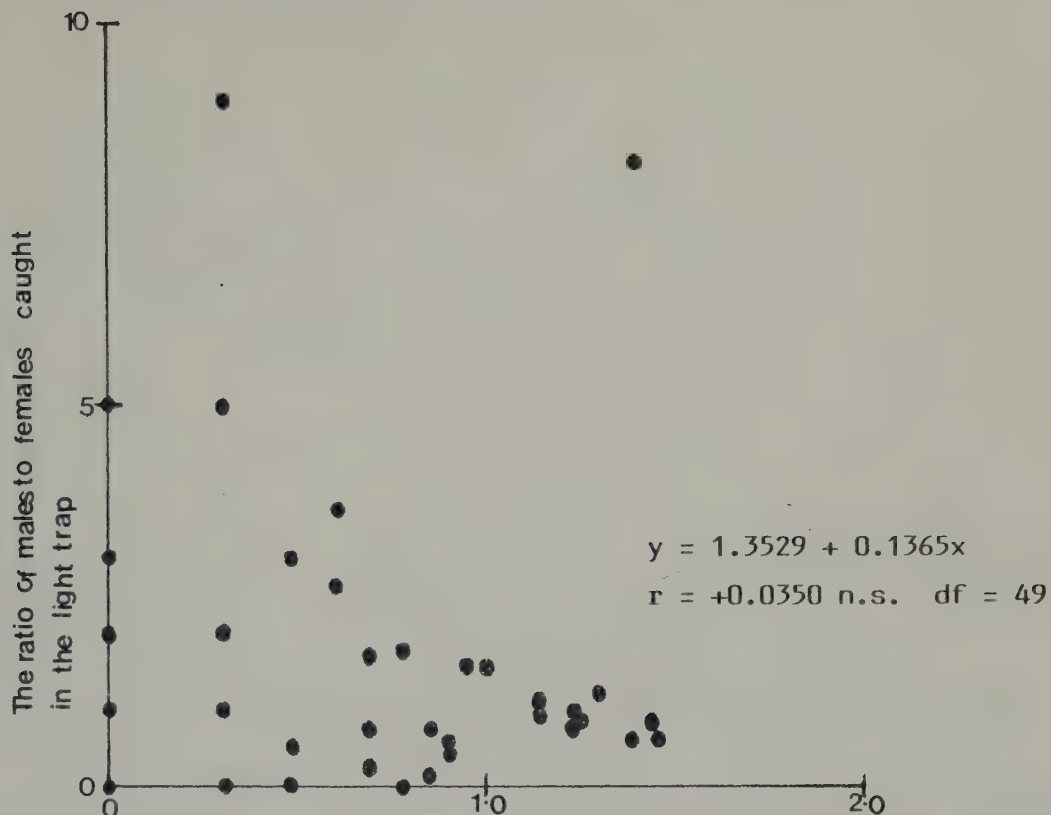


Figure 43 continued — ii- 1984

- a- The ratio of males caught in the light trap plotted against the number of females caught in the light trap.



- b- The ratio of males caught in the pheromone trap plotted against the number of females caught in the light trap.

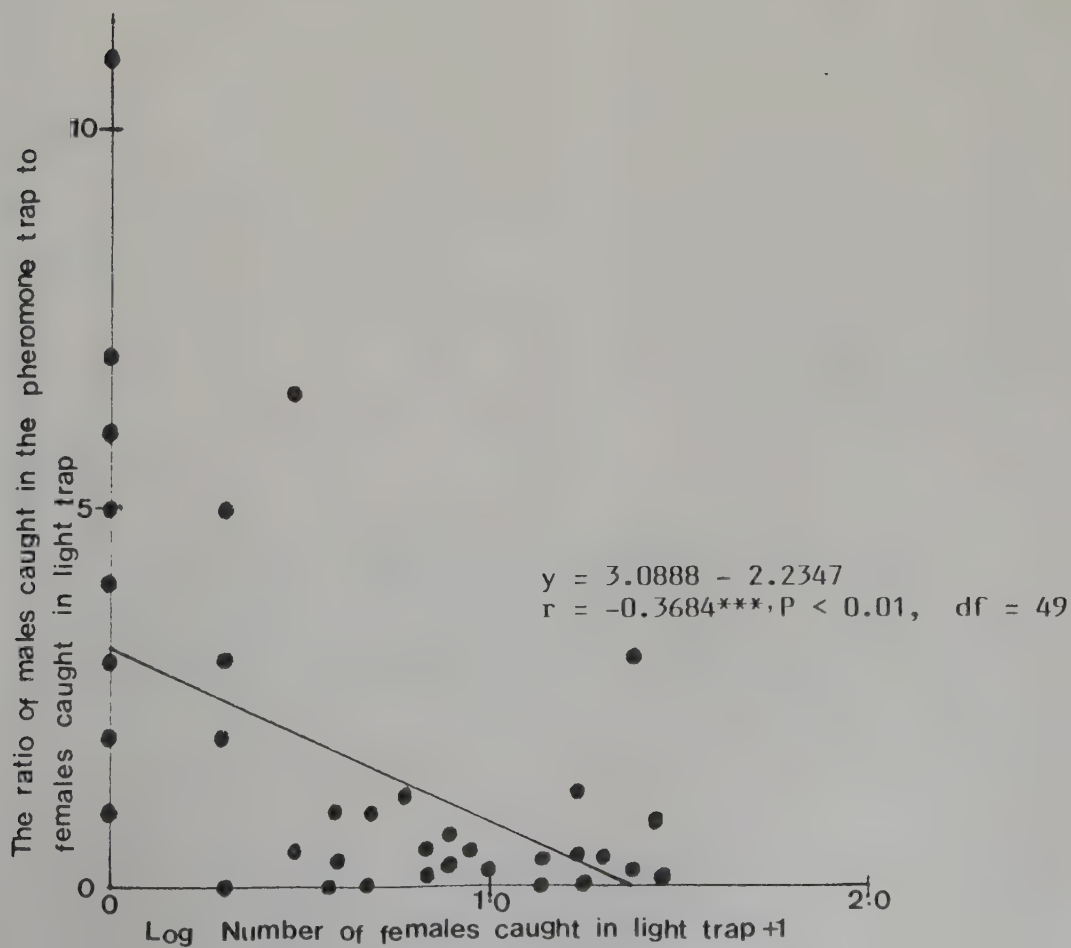
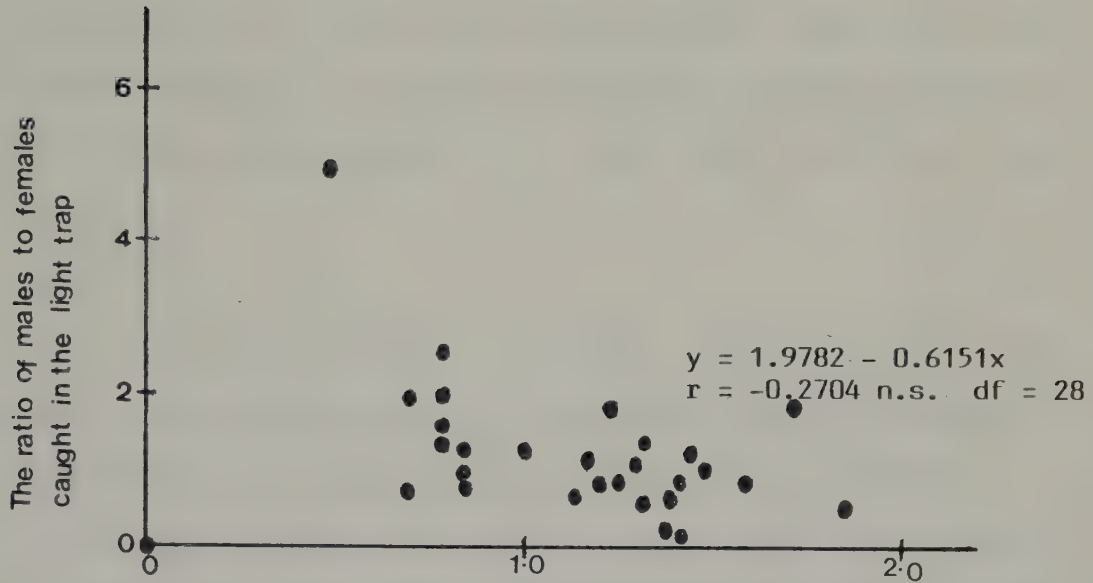
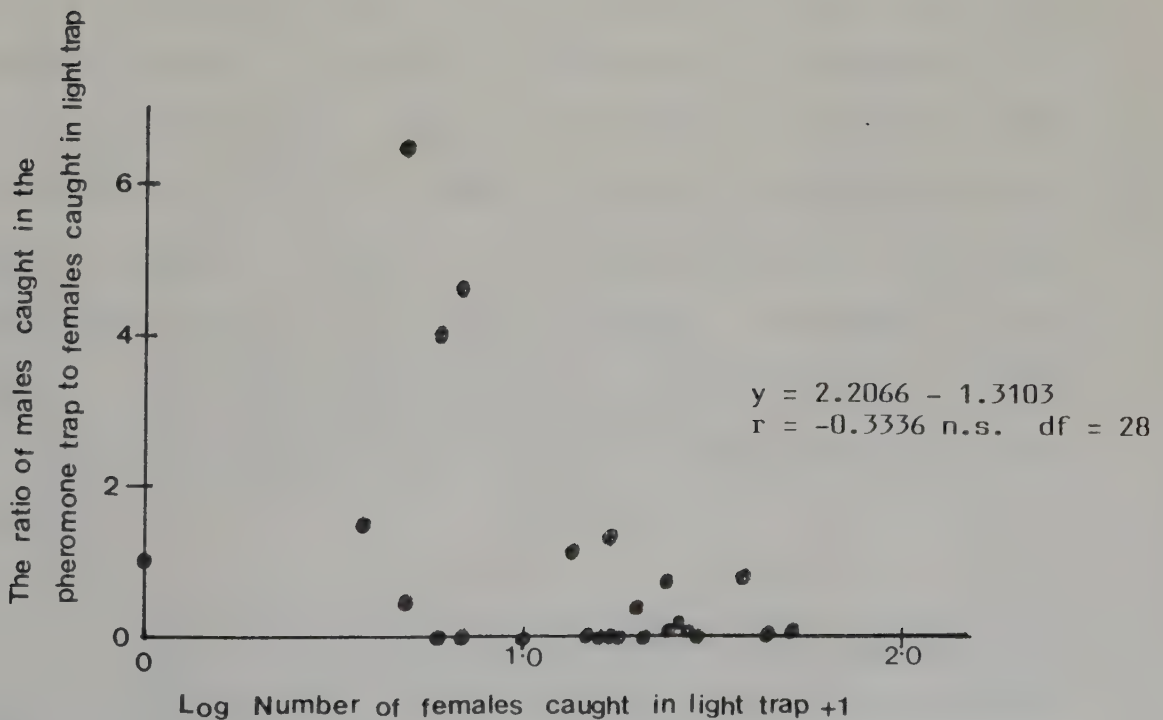


Figure 43 continued — iii-1985

- a- The ratio of males caught in the light trap plotted against the number of females caught in the light trap.



- b- The ratio of males caught in the pheromone trap plotted against the number of females caught in the light trap.



number of the moth sexes caught at the pheromone and light traps was done by multiple regression analysis. Overall, there was a significant positive correlation between the number of males and females caught in the light trap over the three years (Fig. 42ia, iia, iiaa). However, there was no relationship between the ratios of males to female numbers caught in the light trap (Fig. 43ia, iia and iiaa).

The relationship between the number of males caught in the pheromone and light trap catches was variable between the years, in 1982 and 1985, there being no relationship between moth catches in the pheromone and females caught in the light trap (Fig. 42ib and iibb). However, in 1984, male catches in the pheromone trap were significantly positively correlated to the number of females caught in the light trap (Fig. 42iib). Similarly, there was little relationship between the ratio of males caught in the pheromone trap to the number of females caught in the light trap in 1982 and 1985 (Fig. 43ib and iibb) but in 1984, the ratio of male catches to the number of females caught in the light trap was significantly negatively correlated (Fig. 43iib). Similarly, the number of males caught in the pheromone and light traps were not correlated in 1982 and 1985 but were significantly positively correlated in 1984 (Fig. 42iic).

Low male moth catches in the pheromone trap relative to the number of females caught in the light trap could be an indication of mating time for the adult population and/or the physiological status

of the population as a whole. Light traps catch immature, old and sexually mature adult moths whereas a pheromone trap catch, as mentioned earlier, only sexually mature males. Thus, if there is an influx of newly emerged adults there would be a tendency for the catch in the light trap to be higher than that in the pheromone trap. Studies of the age structure of the adult moth catches in the light trap at Ukiriguru over a number of years is necessary in order to establish a better understanding of the trap data.

Equally important is the time of high male catches in the pheromone trap relative to female catches in the light trap as this indicates a period of low trap-female competition and hence an indication of egg laying period depending on crop phenology (Brown and Swaine, 1966; Hartstack, 1979). If this period coincides with the time when the crop is lush and flowering vigorously, inspection of the susceptible crop should be done to ascertain the level of infestation. In the case study, considering the period January to May when the crops, notably cotton, would be at susceptible stages of growth to attack by H. armigera, there were few occasions when peak male catches in the pheromone trap were notably higher compared to the female catches (Fig. 41). For example, in 1984, two important catch peaks were recorded in the pheromone trap. The first peak occurred on the 11th week and this was followed a few weeks later by the second peak in week 15 (Fig. 41b). In both peaks, the number of males trapped in both light and pheromone traps was considerably higher compared to the number of females caught in the light trap (Fig. 43ii). In both cases, crop inspection showed an increase in

the level of egg laying on cotton (Fig. 50i) in the same weeks. However, peak egg laying was recorded two weeks later, thus showing a two-week lag behind between peak male records and oviposition. In contrast, in 1985, several male peaks could be identified in the pheromone trap catch but only the first peak which was recorded in week 5 and 6 could be related to actual crop infestation (Figs. 41c, 43iii and 53i). In this season there was no time lag between the first record of high moth catch in the pheromone trap and the timing of the first infestation. Thus, where possible, both types of traps should be used to compliment each other and trap catches should be supported by crop inspection data to make valid control decisions.

Similar work done in the USA to predict the level of infestation of the tobacco budworm moths (Hartstack and Witz, 1981) showed that early season trap catches can be used to predict the level of infestation, but increasing densities of wild females later in the season cause difficulty in making accurate predictions because of increased competition between the trap and the wild females. This could be the case at Ukiriguru particularly at the peak population numbers between March and May.

6.3.1 Seasonal variation of *H. armigera* populations in WCGA

6.3.1.1. Adult moth emergence in the insectary - In WCGA, the seasonal activity of *H. armigera* starts at the beginning of the short rains in October when moths emerging from diapausing pupae oviposit on Cleome on which the first generation develops (Reed, 1965a). The second generation of the pest population feeds on early sown maize in

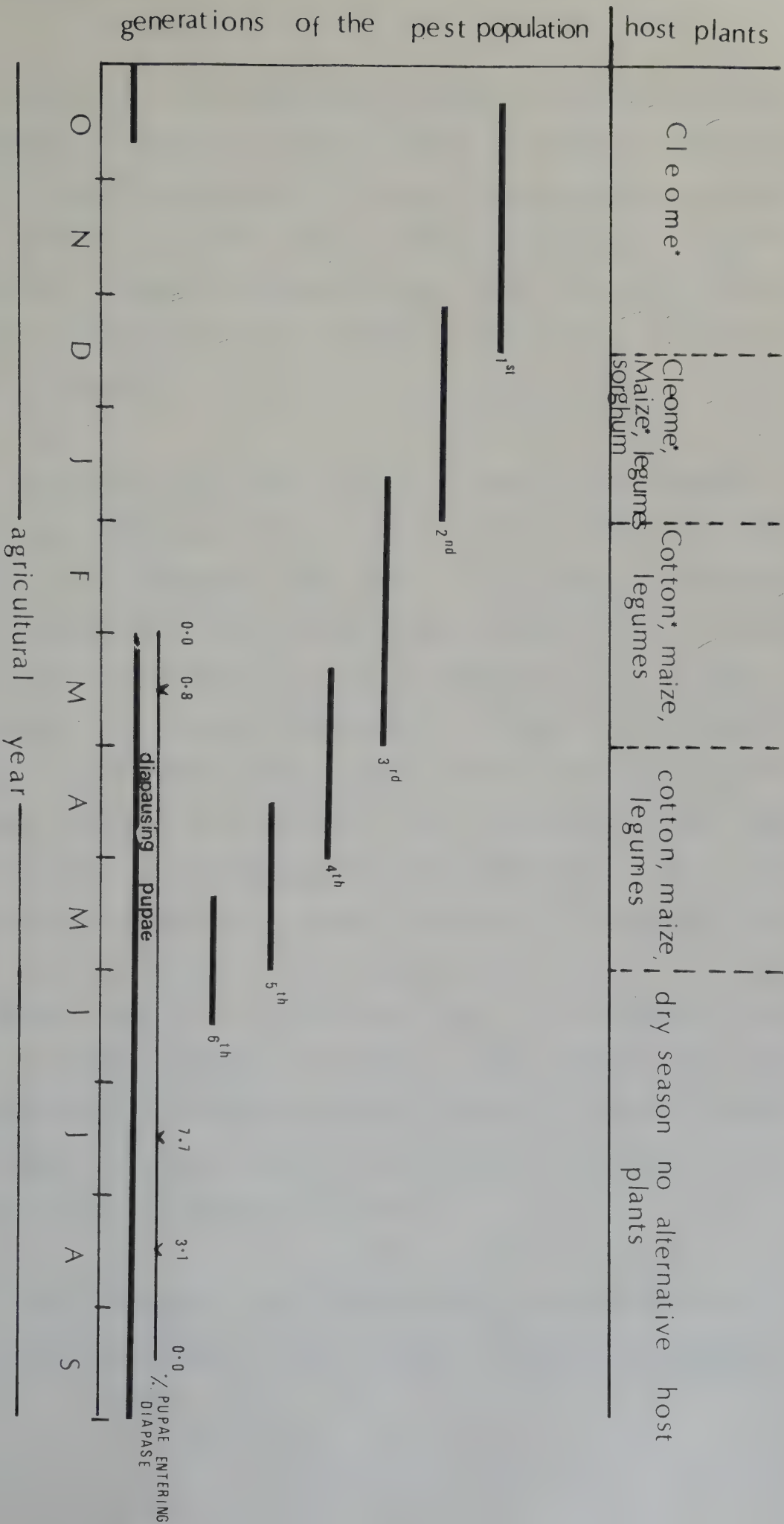
November - December and the 3rd and 4th attack cotton in February - April (Fig. 44). Two more generations develop on late sown cotton, maize and legumes before the dry season in June (Reed, 1965a).

An early report from the Entomologist (Western Region Report for 1960-61) did not record pupal diapause. It could well be that because the overall population density of the pest is very low during the dry season it was not possible to collect sufficient larvae from the field to be able to detect a small proportion of diapausing pupae. However, according to Reed (1965a), H. armigera in WCGA survives the dry season as diapausing pupae and the adults begin to emerge at the beginning of the short rains in October (Fig. 44). In his studies, diapause pupae began to be recorded at a low level, 0.8% in March and the proportion increased gradually to 7.7% in July (Fig. 44). During the dry season neither larvae nor adult moths were recorded.

Pupal diapause has been reported in other parts of Africa (Cowland, 1935; Parsons, 1939; Valentine, 1954; Beeden, 1976), but not in Uganda (Coaker, 1959). Cowland (1935) reported in the Sudan Gezira that 38% to 100% of pupae diapaused in H. armigera although later work, (Balla, 1970) did not record diapause in the pest populations. More recent studies in Sudan by Hackett and Gatehouse (1981) have shown that in H. armigera diapause occurrence was less than 1% under field conditions, and that Heliothis fletcheri also occurred in Sudan and survived the dry season in diapause apparently because it is adapted to survive in rainfall conditions, and Hackett and Gatehouse (1981) concluded that Cowland may have made his observations on the latter species.

Fig 44

The seasonal occurrence of H. armigera in Western Tanzania in the 1960s (Reed, 1965)



During the current studies at Ukiriguru, field collected larvae (Section 3.2) were reared through to adult. On emergence the date of adult emergence was recorded in order to determine pupal duration. The data for the period 1981 to 1985 is summarized in Table 29. Pupae were recorded throughout the year in all the years of study, with few from September to December in each year and many for the rest of the year.

According to Reed (1965a) diapause in pupae in the laboratory at Ukiriguru lasted between 30 to 171 days, but there is also a wide range in the nondiapause pupal period for H. armigera recorded in different countries. Thus, pupae duration varied from 14 to 40 days in Sudan Gezira; 14 to 57 days in Zimbabwe, 12 to 25 days in Tanzania, 14 to 27 days in Uganda and 5 to 8 days in India (Jayaraj, 1981). In the current studies, pupae which took more than 30 days to emerge as adults were considered to be in diapause. Thus, pupal duration for the nondiapausing pupae varied from 10 to 25 days whereas for the diapausing pupae it varied from 32 to 124 days (Table 29). On this criteria, pupae diapause in the population was low, often less than 0.5% in most years (Table 29). Furthermore, there was no regular pattern of diapause. Thus, diapause pupae were recorded from different host plants at different times of the year, and adult emergence occurred between August and October, in the middle of the dry season (Table 29).

Recent changes in the farming system at Ukiriguru (Section 5.1) could have contributed to the low pupal diapause in H. armigera at

Table 29. Pupation period of H. armigera field collected larvae: Larvae collected from different hosts at Ukiriguru and reared to adult in the insectary.

1981

Month	Total Number of pupae observed	Range of pupae duration (days)	Mean pupae duration (days) of non diapause pupae	Number of individuals in diapause	% Diapause (30 + days)	Source of diapause pupae (Host plant)	Duration of diapause (days)	Time of adult emergence from diapause (month)
April	32	15-19	16.5±1.32	0	0.006	Tomato	32	End of August
May	43	12-19	15.2±1.77	0				
June	113	12-23	16.6±1.83	0				
July	175	14-25	17.7±1.45	1				
August	364	12-20	16.6±1.33	0				
Sept	131	14-21	16.6±2.25	0				
Oct	114	12-17	14.7±1.27	0				
Nov	45	14-19	15.8±1.39	0				
Dec	120	13-20	16.3±1.41	0				
<u>1982</u>								
Jan	411	13-20	16.5±1.46	0	0.20	Maize	124	Mid August
Feb	327	12-19	16.5±1.37	0				
March	407	13-22	16.3±1.56	0				
April	414	14-21	16.7±1.48	1				
May	546	10-20	15.6±1.66	0				
June	298	12-19	15.3±1.29	0				
July	458	12-25	15.9±1.48	0				
Aug	394	11-20	15.2±1.48	1				
Sept	347	12-20	15.1±1.29	0	0.25	Chickpea	36	Mid September
Oct	64	12-19	16.4±1.55	0				
Nov	191	14-21	17.2±2.01	0				
Dec	134	13-19	15.5±1.42	0				

Table 29 (Continued)

1983

Month	Total Number of pupae observed	Range of pupae duration (days)	Mean pupae duration (days) of non diapause pupae	Number of individuals in diapause	% Diapause (30 + days)	Source of diapause pupae (Host plant)	Duration of diapause (days)	Time of adult emergence from diapause (month)
Jan	820	11-16	13.6±1.37	0				
Feb	639	11-17	13.5±1.29	0				
March	589	11-17	14.2±1.15	0				
April	275	11-20	15.6±1.60	0				
May	507	10-17	14.0±1.36	0				
June	400	12-20	14.3±1.61	0				
July	1270	12-20	15.5±1.26	3	0.23	Chickpea	48/67/96	September/Mid Oct/End Oct.
Aug	1038	13-20	15.9±1.40	1	0.09	Chickpea	89	November
Sept	571	12-18	15.0±1.28	0				
Oct	202	12-21	15.5±1.98	0				
Nov	463	12-20	14.9±1.58	0				
Dec	348	12-24	17.1±2.19	0				
<u>1984</u>								
Jan	650	14-22	17.7±1.81	0				
Feb	167	13-19	15.3±1.48	0				
March	291	12-24	15.1±1.61	0				
April	680	12-21	16.2±1.53	0				
May	584	12-19	14.7±1.17	0				
June	553	12-18	15.7±1.25	1	0.18	Chickpea	92	Mid September
July	255	13-20	16.6±1.46	1	0.39	Chickpea	41	End August
Aug	361	13-18	15.2±1.29	1	0.27	Chickpea	62	End October
Sept	74	12-16	14.4±1.41	0				
Oct	55	12-20	14.7±2.2	0				
Nov	165	14-21	16.8±1.67	0				
Dec	273	10-18	14.2±1.70	0				

Table 29 (Continued)

1985

Month	Total Number of pupae observed	Range of pupae duration (days)	Mean pupae duration (days) of non diapause pupae	Number of individuals in diapause	% Diapause (30 + days)	Source of pupae (Host plant)	Duration of diapause (days)	Time of adult emergence from diapause (month)
Jan	1069	10-21	16.7±2.75	0				
Feb	237	12-21	17.2±1.83	0				
March	120	10-21	16.2±2.74	0				
April	159	14-21	17.5±1.94	0				
May	233	13-18	15.8±1.29	0				
June	221	14-19	16.5±1.25	0				
July	613	14-25	17.0±1.34	1	0.16	Chickpea	43	Mid August

Ukiriguru, as has occurred in the Sudan Gezira (Balla, 1981) and in Egypt (Salama, 1983). Thus, pupae diapause in WCGA may be facultative, and the availability of suitable host plants in the dry season has been a major factor in the reduced level of diapause. However, it is also probable that diapause recorded in H. armigera in WCGA (Reed, 1965a) involved another species of Heliothis, as the case in the Sudan Gezira (Hackett and Gatehouse, 1981) and this needs investigation.

6.4 Seasonal variation of the pest population from light and pheromone trap moth catches

The number of adult moths caught in a trap in any one night is determined by the behaviour of the insect and the total population available for sampling (Williams, 1940). Hopefully, trap catches should reflect the overall abundance and seasonal activity of the pest population unless behaviour changes considerably.

At Ukiriguru, the light trap has been used to sample the adult population for many years but only the data from 1972-73 to 1984-85 is available. Due to technical problems, the light trap at Ukiriguru was the only one for the whole of WCGA (Fig. 5) and although the catches may give an indication of the seasonal changes of the adult pest population, such information is of limited value because for a mobile pest such as H. armigera there may be considerable variability in the activity and abundance of the pest in time and space within the area and from elsewhere. Thus, from 1982, pheromone traps were used to study the seasonal variation of the pest in different sites

in the WCGA. As mentioned earlier, pheromone traps do not require electricity and skilled labour to operate and are simple to run in comparison to light traps and therefore are suitable for use even in very remote areas where electricity is not available.

The pheromone traps were sited at Ukiriguru, Mabuki, Lubaga, Mwanhala and Bwanga (Fig. 5). The data from these traps is summarized in Figures 45a to d. The pattern of activity and abundance varied between sites but overall, the pest was more abundant during the wet season, December to May, and less so during the dry season, June to November.

In 1982, the traps were sited at Ukiriguru, Mabuki and Lubaga only (Fig. 45a). Moths were recorded throughout the year at all the sites except for a 4-week period between the end of September and October at Lubaga.

In 1983, the trap sites were expanded to include Mwanhala and Bwanga (Fig. 45b). At Ukiriguru and Mabuki the pattern of moth flight was identical, with moths being recorded throughout the year except in September and end of October - beginning of November. At both Lubaga and Bwanga moths were not caught between end of May and December whereas at Mwanhala, moths were recorded throughout the year (Fig. 45b).

Moth catches at the Bwanga site were very low and erratic in 1984, whereas at Ukiriguru and Mwanhala moths were recorded

Fig 45 Seasonal changes in *H. armigera* in WCGA: Evidence from adult moth catches in pheromone traps at Ukiriguru, Mabuki, Lubaga, Mwanhala and Bwanga.

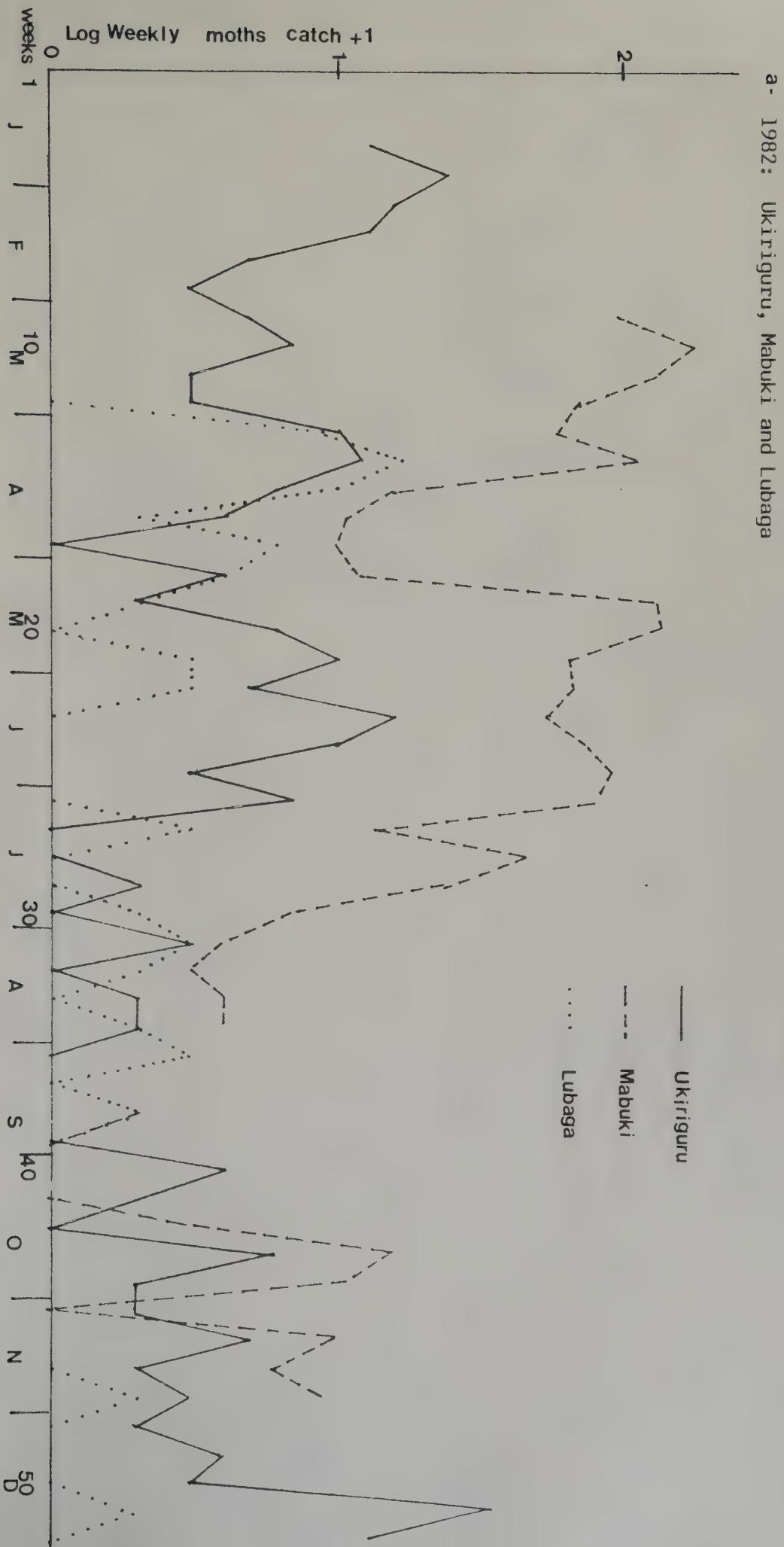


Figure 4 5 continued

b - 1983: Ukiriguru, Mabuki, Lubaga, Mwanhala, and Bwanga

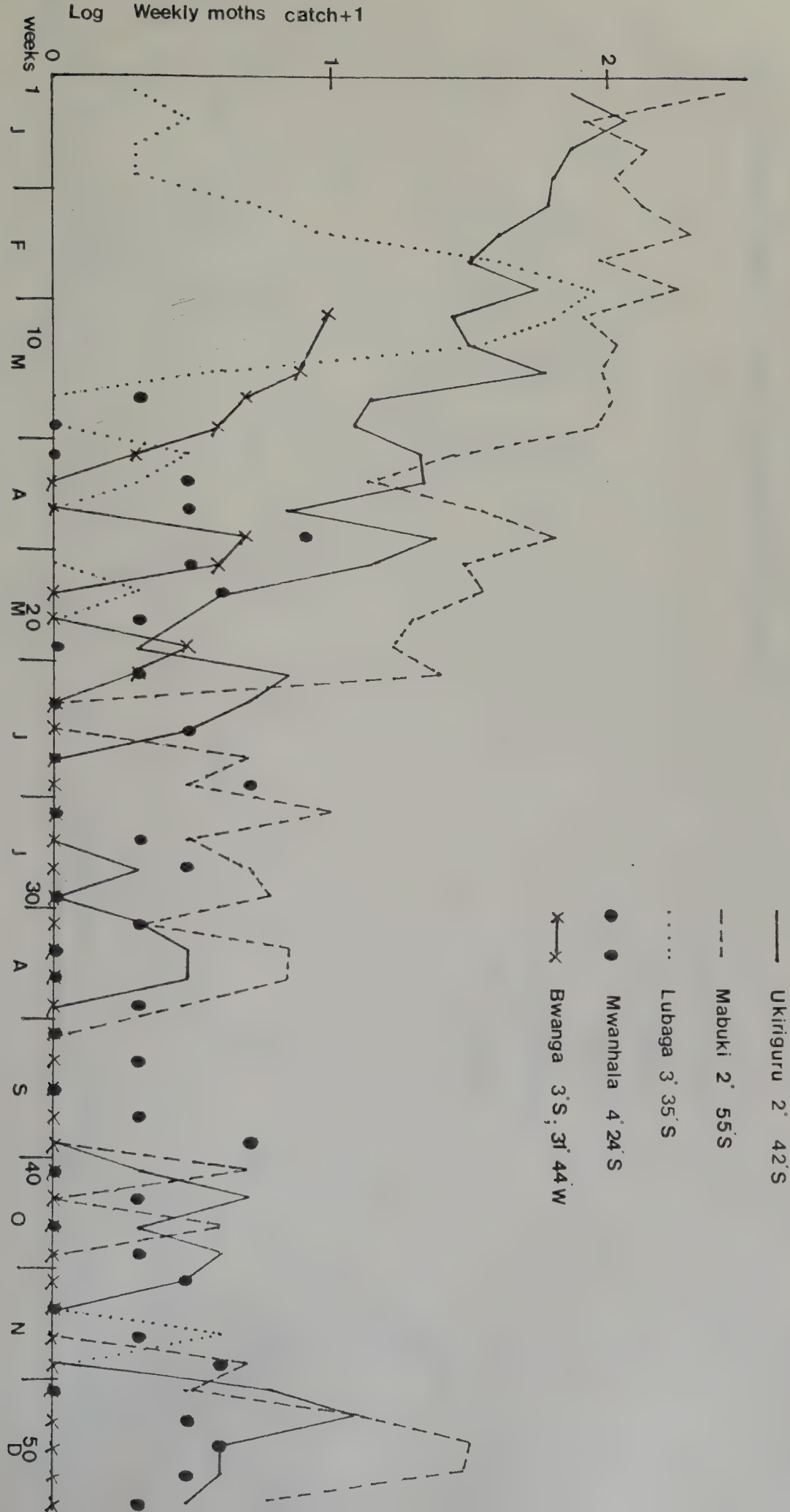


Figure 45 continued

c - 1984 : Ukiriguru, Mabuki, Lubaga, Mwanhala and Bwanga

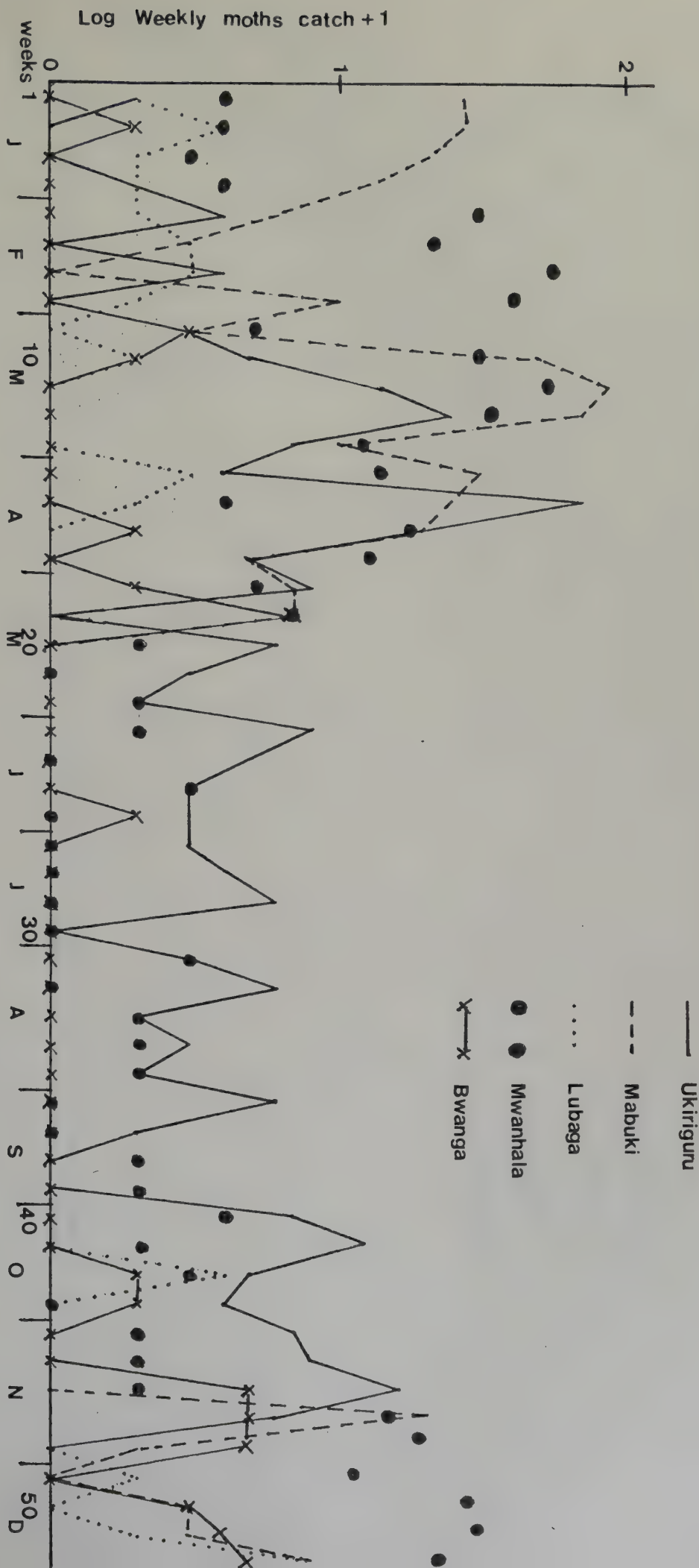


Figure 45 continued

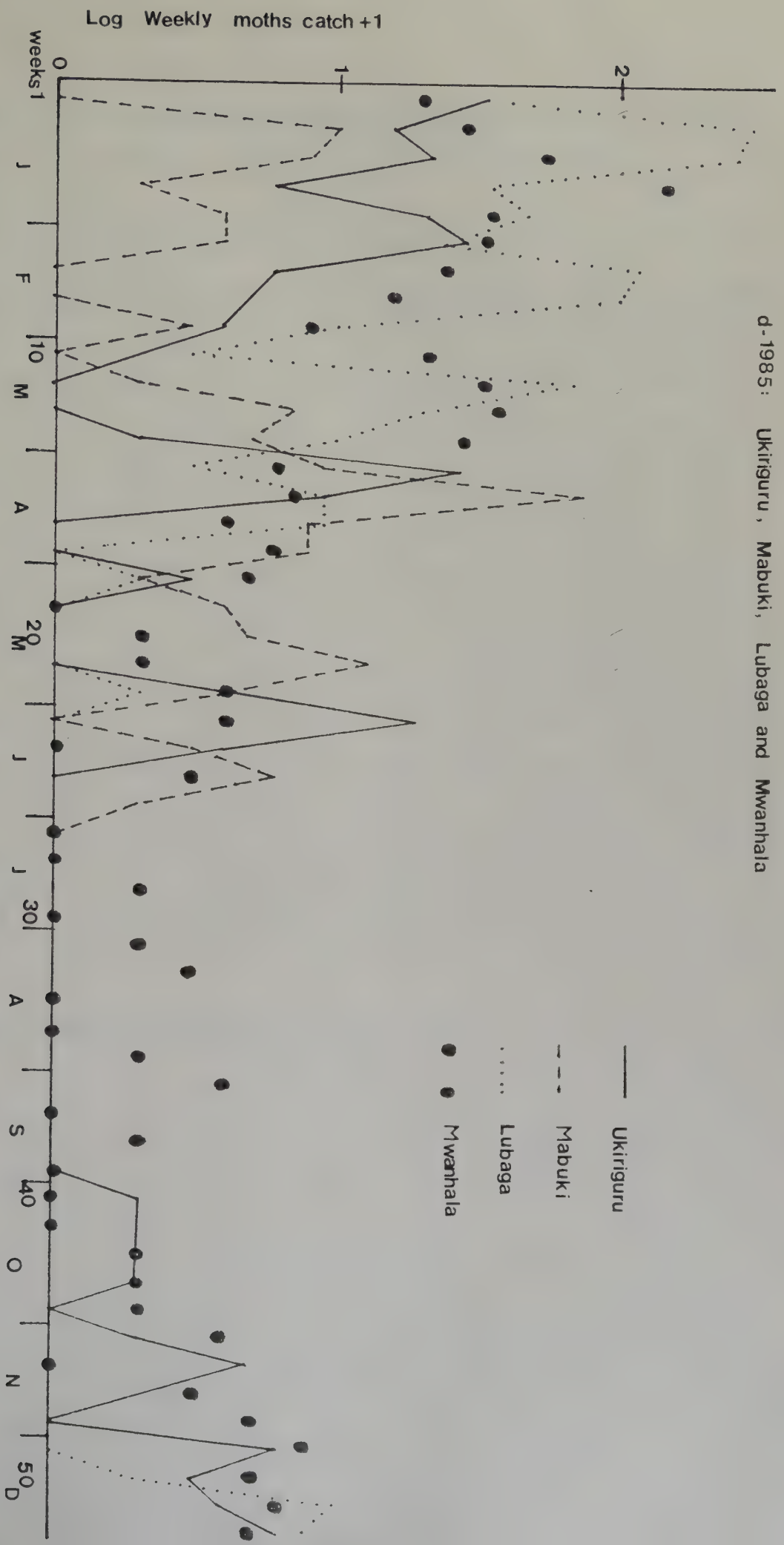


Table 30. Monthly total H. armigera moth catches in the light trap
at Ukiriguru Research Institute 1972-73 to 1984-85 season.

Season	Oct	Nov	Total number of moths caught							Jul	Aug	Sept
			Dec	Jan	Feb	Mar	Apr	May	Jun			
1972-73	2	4	59	69	17	66	19	5	2	1	1	2
1973-74	0	NT	33	16	11	39	24	47	147	83	71	11
1974-75	2	3	35	32	27	29	56	68	12	6	11	12
1975-76	6	4	11	53	16	34	20	55	14	15	23	4
1976-77	6	22	10	17	27	89	98	273	63	33	2	7
1977-78	4	9	32	103	77	71	102	156	44	7	3	3
1978-79	1	6	12	NT	NT	22	69	71	33	22	8	19
1979-80	17	3	33	38	9	21	28	78	62	36	27	30
1980-81	31	5	13	18	10	8	9	95	93	61	32	40
1981-82	26	28	53	80	30	43	106	188	154	18	8	3
1982-83	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
1983-84	NT	NT	NT	23	10	84	327	113	83	31	8	4
1984-85	1	10	70	239	176	98	117	148	156	55	17	9

NT = Not trapping due to power cut-off

throughout the year. At Mabuki, no moths were recorded from mid-May to mid October whereas at Lubaga few moths were recorded and none from mid April to mid october (Fig. 45c).

In 1985, no moths were recorded at Ukiriguru from mid-June to the end of September; at Lubaga from end of June to 1st week of December, at Mabuki from the beginning of June to the end of December. At Mwanhala, moths were recorded throughout the year but the population declined drastically after March (Fig. 45d).

The light trap data for the period 1972-73 to 1984-85 is summarized in Table 30. Overall, there is a strong indication from the pattern and level of activity at Ukiriguru that H. armigera is active throughout the year with a peak in May - June, and with reduced activity and abundance during the dry period July to December. This pattern of moth flight closely reflects the insectary observations made between 1980-81 to 1984-85 seasons (Section 6.3.1.1).

Thus, these studies have been able to demonstrate that H. armigera in WCGA is active throughout the year with low activity during the dry season; and that the pattern of population changes is similar for all sites in WCGA but that the abundance of the pest varies between sites and seasons. Pupal diapause may be present in the population but at a very low level, and therefore the pest population may be surviving on a range of alternative hosts including weeds such as Abutilon sp. and Tridax sp. which were not included in the study.

6.4.1. Comparison of *H. armigera* pheromone and light traps moth catches with the level of infestation and damage in cotton

The moth population was estimated by pheromone and light traps both of which should give an estimate of the ovipositing female population and thus provide an indication of the likely egg and larval populations on the crop. The incubation period of eggs in the laboratory at Ukiriguru is about 3 days (Reed, 1965a) and therefore although there may be a direct relationship between the moth population and the level of eggs recorded in a crop, there may be a time delay between the timing of the build up of the moth population and the subsequent larval population and crop damage. Crop damage was assessed by counting the flared squares and flowers. High egg count may not necessarily lead to high crop damage because natural mortality factors both biotic and abiotic can lead to heavy egg losses. Under conditions of low natural egg mortality there may be a direct relationship between the eggs and larval population.

6.4.1.1. Methodology - Ukiriguru pheromone traps were set up in the cotton scouting trial at Ukiriguru station, Mabuki, Lubaga and Mwanhala sub-stations (Fig. 5) from the beginning of the 1982-83 season to monitor the build up of the adult population and to study the relationship between moth catch in the trap and the level of infestation and damage on cotton. The trial area occupied between 1.5 to 2.0ha of land depending on site. The traps were set up in the trial area immediately after sowing. In 1982-83 season scouting for *H. armigera* eggs, larvae and flared squares began 8 weeks after sowing because this is the stage of plant growth when the first

damaging infestation is expected to occur. However, in 1982-83 season moths were recorded in the traps before the plants formed the first buds and therefore as from 1983-84 season it was decided to start monitoring for eggs, larvae and damage five weeks after sowing (three weeks earlier).

Monitoring for H. armigera eggs and larvae was done twice a week and on the same days each week in the unsprayed plots. Twenty-five plants were picked randomly and examined for eggs and larvae. The whole plant was searched. Flared squares were counted on 50 randomly chosen plants only once a week on the first count in the week when eggs and larvae were also counted. The data from this first weekly count was used to make comparisons with the weekly moth catches (Fig. 46 to 56). Scouting continued up to the end of the second pick at all sites. The data was analysed by multiple correlations and partial regressions to study the relationship between moth catch, crop infestation and damage within the same week and the relationship between moths caught in a week and the level of infestation and damage a week later. The results of the analysis are summarized in Table 31 and Figures 46, 48, 50, 51, 52 and 54.

Comparisons were also made between the weekly moth catches in the light trap and the level of infestation and damage within the week and a week later to study the relationship between moth catches in the light trap and the level of infestation and damage as a means of assessing the reliability of the pheromone traps. Both female and male moths caught in the light trap were used in the study. Light

Table 31. The relationship between H. armigera pheromone and light trap adult moth catches and the level of infestation and damage to cotton in WCGA: 1982-83 to 1984-85 seasons.

31(1) The relationship between light trap moth catches and the level of infestation and damage within the same week and a week later at Ukiriguru in 1983-84 and 1984-85 seasons.

1983-84 season

a-i Female moths, X, in relation to the number of eggs per plant, Y.

X vs Y within the same week	X vs Y measured a week later
$y = 0.0028 + 0.0170x$	$y = 0.0034 + 0.0166x$
$r = +0.380$ n.s., $df = 16$	$r = +0.368$ n.s., $df = 16$

ii Female moths, X, in relation to the number of larval per plant, Y.

$y = 0.0276 + 0.0394x$	$y = 0.0117 + 0.0588x$
$r = +0.320$ n.s., $df = 16$	$r = +0.475^*$, $p = 0.05$, $df = 16$

iii Female moths, X, in relation to the number of flared squares per plant, Y.

$y = 0.0502 + 0.120x$	$y = 0.0289 + 0.147x$
$r = +0.417$ n.s., $df = 16$	$r = +0.508^*$, $p = 0.05$, $df = 16$

b-i Male moths, X, in relation to the number of eggs per plant, Y.

$y = 0.0037 + 0.0147x$	$y = -0.0012 + 0.0184x$
$r = +0.353$ n.s., $df = 16$	$r = +0.454$ n.s., $df = 16$

ii Male moths, X, in relation to the number of larvae per plant, Y.

$y = 0.0166 + 0.0482x$	$y = 0.0198 + 0.0473x$
$r = +0.422$ n.s., $df = 16$	$r = +0.425$ n.s., $df = 16$

iii Male moths, X, in relation to the number of flared squares per plant, Y.

$y = 0.0232 + 0.140x$	$y = 0.0263 + 0.144x$
$r = +0.523^*$, $p = 0.05$, $df = 16$	$r = +0.554^*$, $p = 0.05$, $df = 16$

1984-85 season

a-i Female moths, X, in relation to the number of eggs per plant, Y.

$y = 0.0189 - 0.010x$	$y = -0.0077 + 0.0233x$
$r = -0.012$ n.s., $df = 17$	$r = +0.297$ n.s., $df = 17$

ii Female moths, X, in relation to the number of larvae per plant, Y.

$y = 0.0169 + 0.0223x$	$y = 0.0291 + 0.0133x$
$r = +0.240$ n.s., $df = 17$	$r = +0.138$ n.s., $df = 17$

iii Female moths, X, in relation to the number of flared squares per plant, Y.

$y = 0.0709 + 0.0013x$	$y = 0.0705 + 0.0055x$
$r = +0.010$ n.s., $df = 17$	$r = +0.043$ n.s., $df = 17$

Table 31 (Continued)

31(1) (Continued)

1984-85 seasonb-i Male moths, X, in relation to the number of eggs per plant, Y.

$$y = 0.007 + 0.0096x$$

$$r = +0.103 \text{ n.s., df} = 17$$

$$y = -0.021 + 0.0334x$$

$$r = +0.382 \text{ n.s., df} = 17$$

ii Male moths, X, in relation to the number of larvae per plant, Y.

$$y = -0.005 + 0.037x$$

$$r = +0.341 \text{ n.s., df} = 17$$

$$y = 0.032 + 0.010x$$

$$r = +0.092 \text{ n.s., df} = 17$$

iii Male moths, X, in relation to the number of flared squares per plant, Y.

$$y = 0.078 - 0.005x$$

$$r = -0.034 \text{ n.s., df} = 17$$

$$y = 0.086 - 0.009x$$

$$r = -0.063 \text{ n.s., df} = 17$$

31(2) The relationship between H. armigera pheromone trap adult moth catches and the level of infestation and damage to cotton in WCGA: 1982-83 to 1984-85 seasons:
The relationship between pheromone trap moth catches and the level of infestation (eggs and larvae) and damage (flared squares) within the same week and a week later.

1982-83 season

Site 1 - Ukiriguru

Weekly moth catch (X) in relation to the level of infestation and damage (Y).

X vs Y within the same weekX vs Y measured a week lateri Moth catch vs. the number of eggs per plant

$$y = -0.021 + 0.058x$$

$$r = +0.374 \text{ n.s., df} = 13$$

$$y = -0.013 + 0.051x$$

$$r = +0.334 \text{ n.s., df} = 13$$

ii Moth catch vs. the number of larvae per plant

$$y = -0.054 + 0.102x$$

$$r = +0.568^*, p < 0.05, \text{ df} = 13$$

$$y = -0.013 + 0.051x$$

$$r = +0.651^{**}, p < 0.01, \text{ df} = 13$$

iii Moth catch vs. the number of flared squares per plant

$$y = 0.248 - 0.009x$$

$$r = -0.046 \text{ n.s., df} = 13$$

$$y = 0.284 - 0.035x$$

$$r = -0.174 \text{ n.s., df} = 13$$

Site 2 - Lubaga

Weekly moth catch (X) in relation to the level of infestation and damage (Y).

X vs Y within the same weekX vs Y measured a week lateri Moth catch vs the number of eggs per plant

$$y = 0.032 + 0.062x$$

$$r = +0.478 \text{ n.s. df} = 14$$

$$y = 0.019 + 0.081x$$

$$r = +0.611^*, p < 0.05, \text{ df} = 14$$

Table 31 (Continued)

31(2) (Continued)

ii Moth catch vs. the number of larvae per plant

$$y = 0.076 + 0.055x$$

$$r = +0.436 \text{ n.s., df} = 14$$

$$y = 0.065 + 0.069x$$

$$r = +0.538^*, p = 0.05, \text{ df} = 14$$

iii Moth catch vs the number of flared squares per plant

$$y = 0.137 + 0.095x$$

$$r = +0.504^*, p = 0.05, \text{ df} = 14$$

$$y = 0.112 + 0.131x$$

$$r = +0.691^{***}, p = 0.005, \text{ df} = 14$$

Site 3 - Mwanhala

Weekly moth catch (X) in relation to the level of infestation and damage (Y).

X vs Y within the same weekX vs Y measured a week lateri Moth catch vs the number of eggs per plant

$$y = 0.006 + 0.025x$$

$$r = +0.496 \text{ n.s., df} = 10$$

$$y = 0.012 + 0.017x$$

$$r = +0.316 \text{ n.s., df} = 10$$

ii Moth catch vs the number of larvae per plant

$$y = 0.175 - 0.043x$$

$$r = -0.258 \text{ n.s., df} = 10$$

$$y = 0.160 - 0.036x$$

$$r = -0.257 \text{ n.s., df} = 10$$

iii Moth catch vs the number of flared squares per plant

$$y = 0.103 + 0.051x$$

$$r = +0.411 \text{ n.s., df} = 10$$

$$y = 0.102 + 0.035x$$

$$r = +0.290 \text{ n.s., df} = 10$$

1983-84 season

Site 1 - Ukiriguru

Weekly moth catch (X) in relation to the level of infestation and damage (Y)

X vs Y within the same weekX vs Y measured a week lateri Moth catch vs the number of eggs per plant

$$y = 0.008 + 0.011x$$

$$r = +0.355 \text{ n.s., df} = 14$$

$$y = -0.006 + 0.024x$$

$$r = +0.672^{***}, p = 0.005, \text{ df} = 14$$

ii Moth catch vs the number of larvae per plant

$$y = 0.042 + 0.026x$$

$$r = +0.245 \text{ n.s., df} = 14$$

$$y = 0.031 + 0.035x$$

$$r = +0.334 \text{ n.s., df} = 14$$

iii Moth catch vs the number of flared squares per plant

$$y = 0.059 + 0.107x$$

$$r = +0.482 \text{ n.s., df} = 14$$

$$y = 0.030 + 0.135x$$

$$r = +0.607^*, p = 0.05, \text{ df} = 14$$

Table 31 (Continued)

31(2) (Continued)

Site 2 - Mabuki

Weekly moth catch (X) in relation to the level of infestation and damage (Y).

<u>X vs Y within the same week</u>	<u>X vs Y measured a week later</u>
<u>i</u> Moth catch vs the number of eggs per plant	
$y = -0.004 + 0.017x$	$y = -1.019 + 0.013x$
$r = +0.422$ n.s., $df = 15$	$r = +0.289$ n.s., $df = 15$
<u>ii</u> Moth catch vs the number of larvae per plant	
$y = 0.050 + 0.088x$	$y = 0.029 + 0.100x$
$r = +0.464$ n.s., $df = 15$	$r = +0.511^*$, $p = 0.05$, $df = 15$
<u>iii</u> Moth catch vs the number of flared squares per plant	
$y = 0.031 + 0.148x$	$y = 0.058 + 0.113x$
$r = +0.590^{**}$, $p = 0.01$, $df = 15$	$r = +0.416$ n.s., $df = 15$

Site 3 - Mwanhala

Weekly moth catch (X) in relation to the level of infestation and damage (Y)

<u>X vs Y within the same week</u>	<u>X vs Y measured a week later</u>
<u>i</u> Moth catch vs the number of eggs per plant	
$y = -0.001 + 0.057x$	$y = -0.009 + 0.064x$
$r = +0.469$ n.s., $df = 12$	$r = +0.507$ n.s., $df = 12$
<u>ii</u> Moth catch vs the number of larvae per plant	
$y = 0.143 + 0.057x$	$y = 0.095 + 0.108x$
$r = +0.343$ n.s., $df = 12$	$r = +0.619^*$, $p = 0.05$, $df = 12$
<u>iii</u> Moth catch vs the number of flared squares per plant	
$y = 0.163 + 0.076x$	$y = 0.095 + 0.148x$
$r = +0.323$ n.s., $df = 12$	$r = +0.600^*$, $p = 0.05$, $df = 12$

1984 -85 season

Site 1 - Ukiriguru

Weekly moth catch (X) in relation to the level of infestation and damage (Y)

<u>X vs Y within the same week</u>	<u>X vs Y measured a week later</u>
<u>i</u> Moth catch vs the number of eggs per plant	
$y = -0.006 + 0.033x$	$y = -0.007 + 0.032x$
$r = +0.547^*$, $p = 0.05$, $df = 17$	$r = +0.509^*$, $p = 0.05$, $df = 17$

Table 31 (Continued)

31(2) (Continued)

Site 1 - Ukiriguru (continued)

ii Moth catch vs the number of larvae per plant

$$y = 0.030 + 0.017x$$

$$r = +0.234 \text{ n.s., df} = 17$$

$$y = 0.026 + 0.019x$$

$$r = +0.271 \text{ n.s., df} = 17$$

iii Moth catch vs the number of flared squares per plant

$$y = 0.081 + 0.017x$$

$$r = +0.168 \text{ n.s., df} = 17$$

$$y = 0.081 + 0.010x$$

$$r = +0.098 \text{ n.s., df} = 17$$

Site 2 - Mabuki

Weekly moth catch (X) in relation to the level of infestation and damage (Y)

X vs Y within the same weekX vs Y measured a week lateri Moth catch vs the number of eggs per plant

$$y = 0.014 + 0.0001x$$

$$r = +0.001 \text{ n.s., df} = 16$$

$$y = 0.002 + 0.020x$$

$$r = +0.456 \text{ n.s., df} = 16$$

ii Moth catch vs the number of larvae per plant

$$y = 0.018 + 0.008x$$

$$r = +0.121 \text{ n.s., df} = 16$$

$$y = -0.001 + 0.045x$$

$$r = +0.690^{***}, p = 0.005 \text{ df} = 16$$

iii Moth catch vs the number of flared squares per plant

$$y = 0.049 + 0.018x$$

$$r = +0.213 \text{ n.s., df} = 14$$

$$y = 0.013 + 0.063x$$

$$r = +0.419 \text{ n.s., df} = 14$$

Site 3 - Lubaga

Weekly moth catch (X) in relation to the level of infestation and damage (Y)

X vs Y within the same weekX vs Y measured a week lateri Moth catch vs. the number of eggs per plant

$$y = 0.149 - 0.002x$$

$$r = -0.010 \text{ n.s., df} = 16$$

$$y = 0.147 + 0.011x$$

$$r = +0.071 \text{ n.s., df} = 16$$

ii Moth catch vs the number of larvae per plant

$$y = 0.095 - 0.018x$$

$$r = -0.310 \text{ n.s., df} = 16$$

$$y = 0.093 - 0.014x$$

$$r = -0.229 \text{ n.s., df} = 16$$

iii Moth catch vs the number of flared squares per plant

$$y = 0.165 - 0.060x$$

$$r = -0.500^*, p = 0.05, \text{ df} = 16$$

$$y = 0.160 - 0.47x$$

$$r = -0.414 \text{ n.s., df} = 16$$

Table 31 (Continued)

31(2) (Continued)

Site 4 - Mwanhala

Weekly moth catch (X) in relation to the level of infestation and damage (Y)

<u>X vs Y within the same week</u>	<u>X vs Y measured a week later</u>
<u>i</u> Moth catch vs the number of eggs per plant $y = -0.0001 + 0.026x$ $r = +0.390$ n.s., df = 12	$y = -0.015 + 0.036x$ $r = +0.468$ n.s., df = 12
<u>ii</u> Moth catch vs the number of larvae per plant $y = 0.069 - 0.009x$ $r = -0.076$ n.s., df = 12	$y = 0.075 - 0.013x$ $r = -0.093$ n.s., df = 12
<u>iii</u> Moth catch vs the number of flared squares per plant $y = 0.099 - 0.020x$ $r = -0.123$ n.s., df = 12	$y = 0.125 - 0.038x$ $r = -0.199$ n.s., df = 12

31(3) The relationship between the level of infestation (eggs and larvae) and damage (flared squares) per plant within the same week and a week later

1982-- 83 season

Site 1 - Ukiriguru

<u>X vs Y within the same week</u>	<u>X vs Y measured a week later</u>
<u>i</u> Number of eggs per plant, (X) in relation to the number of larvae and flared squares per plant (Y). Eggs per plant vs number of larvae per plant $y = 0.046 + 0.690x$ $r = +0.602^*$, $p < 0.05$, df = 13	$y = 0.044 + 0.617x$ $r = +0.558^*$, $p = 0.05$, df = 13
Eggs per plant vs number of flared squares per plant $y = 0.252 - 0.286x$ $r = -0.222$ n.s., df = 13	$y = 0.209 + 0.550x$ $r = +0.459$ n.s., df = 13
<u>ii</u> Number of larvae per plant (X) in relation to the number of flared squares per plant (Y). $y = 0.192 + 0.408x$ $r = +0.355$ n.s., df = 13	$y = 0.190 + 0.491x$ $r = +0.418$ n.s., df = 13

Site 2 - Lubaga

<u>X vs Y within the same week</u>	<u>X vs Y measured a week later</u>
<u>i</u> Number of eggs per plant (X) in relation to the number of larvae and flared squares per plant, (Y). Eggs per plant vs number of larvae per plant $y = 0.098 + 0.178x$ $r = +0.183$ n.s., df = 14	$y = 0.095 + 0.188x$ $r = +0.198$ n.s., df = 14

Table 31 (Continued)

Site 2 - Lubaga (continued)

Eggs per plant vs number of flared squares per plant

$$y = 0.123 + 1.03x$$

$$r = +0.719***, p < 0.005, df = 14$$

$$y = 0.095 + 0.188x$$

$$r = +0.453 \text{ n.s.}, df = 14$$

ii Number of larvae per plant (X) in relation to the number of flared squares per plant, (Y).

$$y = 0.082 + 1.05x$$

$$r = +0.709***, p < 0.005, df = 14$$

$$y = 0.097 + 0.889x$$

$$r = +0.580*, p = 0.05, df = 14$$

Site 3 - Mwanhala

X vs Y within the same weekX vs Y measured a week later

i Number of eggs per plant (X), in relation to the number of larvae and flared squares per plant (Y).

Eggs per plant vs number of larvae per plant

$$y = 0.175 - 1.121x$$

$$r = -0.344 \text{ n.s.}, df = 10$$

$$y = 0.130 + 1.026x$$

$$r = +0.313 \text{ n.s.}, df = 10$$

Eggs per plant vs number of flared squares per plant

$$y = 0.129 + 0.054x$$

$$r = +0.022 \text{ n.s.}, df = 10$$

$$y = 0.108 + 0.682x$$

$$r = +0.303 \text{ n.s.}, df = 10$$

ii Number of larvae per plant (X), in relation to the number of flared squares per plant (Y).

$$y = 0.049 + 0.533x$$

$$r = +0.713**, p = 0.01, df = 10$$

$$y = 0.074 + 0.299x$$

$$r = +0.367 \text{ n.s.}, df = 10$$

1983-84 season

Site 1 - Ukiriguru

X vs Y within the same weekX vs Y measured a week later

i Number of eggs per plant (X) in relation to the number of larvae and flared squares per plant (Y).

Eggs per plant vs the number of larvae per plant

$$y = 0.026 + 2.13x$$

$$r = +0.781****, p < 0.001, df = 14$$

$$y = 0.030 + 1.930x$$

$$r = +0.707***, p = 0.005, df = 14$$

Eggs per plant vs the number of flared squares per plant

$$y = 0.069 + 5.25x$$

$$r = +0.849****, p < 0.001, df = 14$$

$$y = 0.095 + 3.920x$$

$$r = +0.633**, p = 0.01, df = 14$$

ii Number of larvae per plant (X) in relation to the number of flared squares per plant, (Y).

$$y = 0.0288 + 2.110x$$

$$r = +0.931****, p < 0.001, df = 14$$

$$y = 0.407 - 1.37x$$

$$r = -0.179 \text{ n.s.}, df = 14$$

Table 31 (Continued)
31(2) Continued
Site 2 - Mabuki

	<u>X vs Y within the same week</u>	<u>X vs Y measured a week later</u>
<u>i</u>	Number of eggs per plant (X) in relation to the number of larvae and flared squares per plant (Y). Eggs per plant vs the number of larvae per plant	
	$y = 0.098 + 2.06x$ $r = +0.431$ n.s., $df = 15$	$y = 0.124 + 0.966x$ $r = +0.218$ n.s., $df = 15$
	Eggs per plant vs the number of flared squares per plant	
	$y = 0.147 + 1.833x$ $r = +0.300$ n.s., $df = 15$	$y = 0.127 + 3.480x$ $r = +0.570^*$, $p = 0.05$, $df = 15$
<u>ii</u>	Number of larvae per plant (X) in relation to the number of flared squares per plant, (Y).	
	$y = 0.055 + 0.925x$ $r = +0.724^{****}$, $p = 0.001$, $df = 15$	$y = 0.070 + 0.792x$ $r = +0.614^{**}$, $p = 0.01$, $df = 15$

Site 3 - Mwanhala

	<u>X vs Y within the same week</u>	<u>X vs Y measured a week later</u>
<u>i</u>	Number of eggs per plant (X) in relation to the number of larvae and flared squares per plant, (Y). Eggs per plant vs number of larvae per plant	
	$y = 0.173 + 0.420x$ $r = +0.305$ n.s., $df = 12$	$y = 0.168 + 0.675x$ $r = +0.530$ n.s., $df = 12$
	Eggs per plant vs number of flared squares per plant	
	$y = 0.204 + 0.525x$ $r = +0.269$ n.s., $df = 12$	$y = 0.200 + 0.719x$ $r = +0.371$ n.s., $df = 12$
<u>ii</u>	Number of larvae per plant (X) in relation to the number of flared squares per plant, (Y).	
	$y = 0.018 + 1.080x$ $r = +0.821^{****}$, $p < 0.001$, $df = 12$	$y = 0.022 + 1.06x$ $r = +0.818^{***}$, $p = 0.005$, $df = 12$

1984-85 season

Site 1 - Ukiriguru

	<u>X vs Y within the same week</u>	<u>X vs Y measured a week later</u>
<u>i</u>	Number of eggs per plant (X) in relation to the number of larvae and flared squares per plant, (Y). Eggs per plant vs number of larvae per plant	
	$y = 0.036 + 0.238x$ $r = +0.197$ n.s., $df = 17$	$y = 0.032 + 0.555x$ $r = +0.472^*$, $p = 0.05$, $df = 17$
	Eggs per plant vs number of flared squares per plant	
	$y = 0.094 - 1.018x$ $r = -0.113$ n.s., $df = 17$	$y = 0.080 + 0.935x$ $r = +0.239$ n.s., $df = 17$

Table 31 (Continued)

31(2) Continued

Site 1 - Ukiriguru (continued) 1984-85 season

ii Number of larvae per plant (X) in relation to the number of flared squares per plant, (Y).

$$y = 0.062 + 0.732x$$

$$r = +0.608^{**}, p = 0.01, df = 17$$

$$y = 0.076 + 0.271x$$

$$r = +0.237 \text{ n.s.}, df = 17$$

Site 2 - Mabuki

X vs Y within the same weekX vs Y measured a week later

i Number of eggs per plant (X) in relation to the number of larvae and flared squares per plant, (Y).

Eggs per plant vs number of larvae per plant

$$y = 0.007 + 1.12x$$

$$r = +0.797^{****}, p < 0.001, df = 16$$

$$y = 0.025 - 0.055x$$

$$r = -0.040 \text{ n.s.}, df = 16$$

Eggs per plant vs number of flared squares per plant

$$y = 0.018 + 2.669x$$

$$r = +0.842^{****}, p < 0.001, df = 14$$

$$y = 0.046 + 1.036x$$

$$r = +0.332 \text{ n.s.}, df = 14$$

ii Number of larvae per plant (X) in relation to the number of flared squares per plant, (Y)

$$y = 0.018 + 1.570x$$

$$r = +0.682^{**}, p < 0.01, df = 14$$

$$y = 0.054 + 0.316x$$

$$r = +0.141 \text{ n.s.}, df = 14$$

Site 3 - Lubaga

X vs Y within the same weekX vs Y measured a week later

i Number of eggs per plant (X) in relation to the number of larvae and flared squares per plant, (Y).

Eggs per plant vs number of larvae per plant

$$y = 0.091 - 0.066x$$

$$r = -0.180 \text{ n.s.}, df = 16$$

$$y = 0.061 + 0.117x$$

$$r = +0.317 \text{ n.s.}, df = 16$$

Eggs per plant vs number of flared squares per plant

$$y = 0.047 + 0.415x$$

$$r = +0.593^*, p = 0.05, df = 16$$

$$y = 0.084 + 0.115x$$

$$r = +0.164 \text{ n.s.}, df = 16$$

ii Number of larvae per plant (X) in relation to the number of flared squares per plant, (Y)

$$y = 0.087 + 0.259x$$

$$r = +0.142 \text{ n.s.}, df = 16$$

$$y = 0.139 - 0.388x$$

$$r = -0.212 \text{ n.s.}, df = 16$$

Site 4 - Mwanhala

X vs Y within the same weekX vs Y measured a week later

i Number of eggs per plant (X) in relation to the number of larvae and flared squares per plants, (Y).

Eggs per plant vs number of larvae plant

$$y = 0.041 + 0.481x$$

$$r = +0.276 \text{ n.s.}, df = 12$$

$$y = 0.026 + 0.846x$$

$$r = +0.461 \text{ n.s.}, df = 12$$

Table 31 (Continued)

31(2) Continued

Site 4 - Mwanhala (Continued) 1984-85 season

i (continued)

Eggs per plant vs number of flared squares per plant

$$y = 0.041 + 0.942x$$

$$r = +0.391 \text{ n.s., } df = 12$$

$$y = 0.063 + 0.434x$$

$$r = +0.178 \text{ n.s., } df = 12$$

ii Number of larvae per plant (X) in relation to the number of flared squares per plant, (Y).

$$y = 0.002 + 1.24x$$

$$r = +0.895****, p < 0.001, df = 12$$

$$y = 0.071 + 0.141x$$

$$r = +0.104 \text{ n.s., } df = 12$$

trap catches in 1983-84 and 1984-85 seasons were used and the regression equations are shown in Tables 31(1).

6.4.1.2 Results and discussions

6.4.1.2.1. Efficiency of the pheromone trap to monitor *H. armigera* infestation compared with the light trap (Ukiriguru 1983-84 and 1984-85 - Overall, the pheromone trap was more sensitive in estimating the proportion of the ovipositing female population. Moth catches in the pheromone trap were more positively correlated to the level of infestation than were the light trap catches in both seasons (Table 31(1) 31(2) Ukiriguru 1983-84 & 1984-85). Similar observations were made in the USA (Hendricks and Hartstack, 1978) where pheromone and light traps were used to monitor and initiate control of *H. zea* Boddie and *H. virescens*. Ukiriguru traps can therefore be used to monitor *H. armigera* infestations over many sites in WCGA.

6.4.1.2.2 The relationship between moth catches in the pheromone trap and cotton crop infestation and damage - The pest population changed and the level of infestation and damage varied between seasons and sites (Fig. 46 to 56) and Table 31(2)). However, there is evidence from the study that at Ukiriguru (Fig. 46iia to c; and 50iii to iv), Lubaga (Fig. 48ii and iii), Mabuki (Fig. 51ii and iii and 54iii and iv) and Mwanhala (Fig. 52iii and iv) weekly moth catches in the pheromone trap were positively correlated to the level of infestation and damage. The number of moths caught in a week were most significantly positively correlated to the level of infestation

assessed a week later, thus showing a one-week lag between the timing of the peak moth catch and the build up of the infestation in the crop (Figs. 46iiia, 48iia to c, 50iiia and b, 52iii and 54iii). In one case, (Fig. 51iia and b), there was a significant positive correlation between the weekly moth catch and the level of infestation and damage within the same week and no time lag was observed. In all cases, significant positive relationship between the level of infestation and moth catch was observed only when 10 or more moths were recorded in the week. Thus, 10 moths per week appear to be the threshold to require crop inspection to establish the level of infestation.

The numbers of eggs and larval populations were more significantly positively correlated in counts done within the same week than when the larvae population was assessed a week later (Table 31(3), Fig. 46iiib, 48iiia, 50iva, 54iva), thus showing lack of time lag between the two stages of the pest population which measure the level of infestation. Similarly, the weekly levels of infestation and damage were more significantly positively correlated than comparisons made between the level of infestation in a week and the level of damage on a week later (Table 31(3), Figs. 48iiia and b, 50ivb and c, 51iii, 52iv and 54ivb and c).

This implies that, whereas moth trapping can be used to give a one week advance warning, lack of time lag between the build up of the infestation and damage means that control measures have to be implemented within the same week once a certain level of infestation

is reached in order to prevent further damage and hence crop loss.

Heliothis pheromone trapping and crop monitoring done elsewhere have shown contradictory trends in USA and Australia. Rothschild et al (1981) in Australia did not observe a 'lag' effect in the relationship between the numbers of adult male H. armigera catches in pheromone traps and eggs laid in the crop. However, in the USA, results with H. zea and H. virescens varied. Hendricks and Hartstack (1978) observed a drift whereby peak captures occurred 3 to 4 days before or after egg laying, whereas Tingle and Mitchell (1981) observed a much longer prolonged drift of 1 to 2 weeks after peak moth catches. Riedl and Croft (1974) and Campion (1983) in discussing the problems of quantitative monitoring suggested that the failure to be able to relate catch to actual crop infestation could partly be due to pheromone traps drawing insects from outside the designated crop area, thus providing misleading information about the population density within the crop which could be the case at Ukiriguru, (Fig. 53) Lubaga (Fig. 55) and Mwamhala (56).

The effect of rainfall on the build up of the pest population varied between sites and seasons possibly due to differences in the amount and distribution of the rain. Heavy rains had a very significant negative impact on the number of moths caught and the build up of the level of infestation in the cotton crop (Fig. 46iia and b). However, moderate rainfall favoured the overall build up of the pest population. The number of moths caught per week and the build up of the level of infestation was shown to be significantly

positively correlated to the amount of rainfall at a number of the sites (Fig. 48iia & b; 52ii, 54ii).

In conclusion, pheromone trap data should not be used to decide the need to apply a chemical treatment. The catch should be used as a signal to monitor the level of infestation and damage in a crop and relate the crop inspection data to an economic threshold (Alford, et al, 1979; Bourdouxhe, 1980; Campion and Nesbitt, 1981). The stage of plant growth and weather conditions are equally important (Parencia, et al, 1962; Hartstack, 1979; Campion and Nesbitt, 1981). For example, high moth catches early in the season when the crop is still at its vegetative phase, as was shown in this study, does not pose a threat to the crop. The same applies to high moth records towards the end of the season when the crop is already set and mature. Similarly, dry weather conditions (Fig. 53) can render plants less attractive for oviposition and thus high moth catches may not necessarily lead to high crop infestation.

Fig 46

- i- The pattern of *H. armigera* level of infestation and damage on cotton and adult male moth catches in a pheromone trap at Ukiriguru in 1982-83 season.

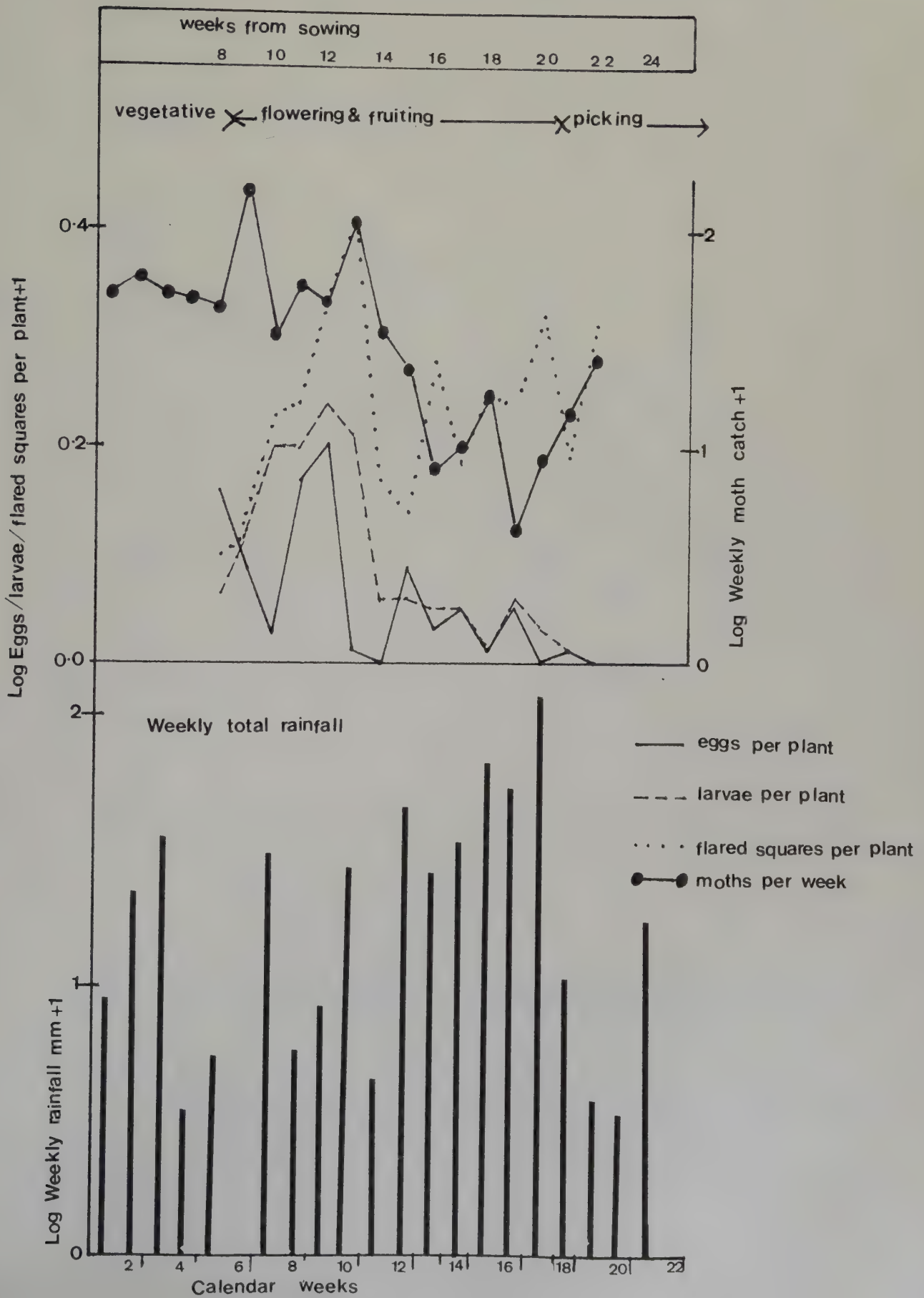
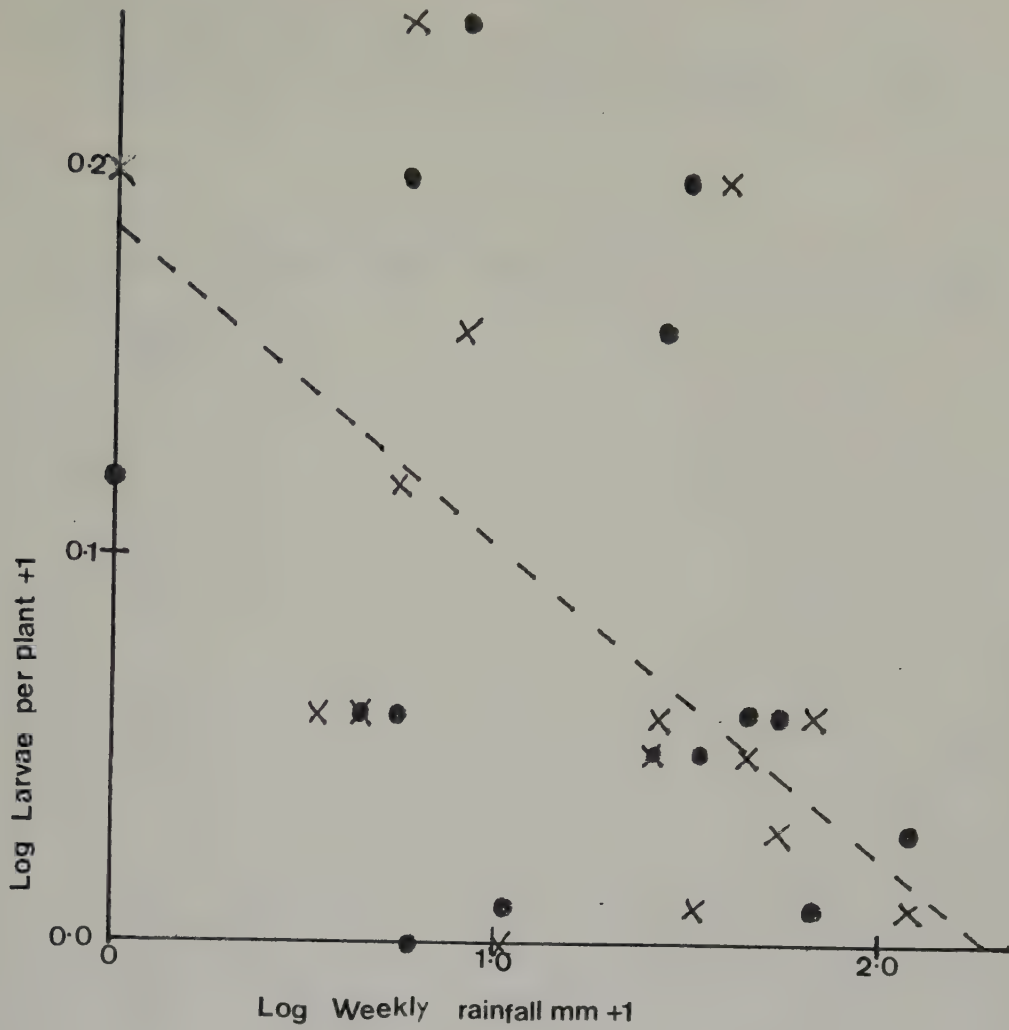


Figure 46

— ii continued

b- Amount of rainfall in relation to larval population per plant



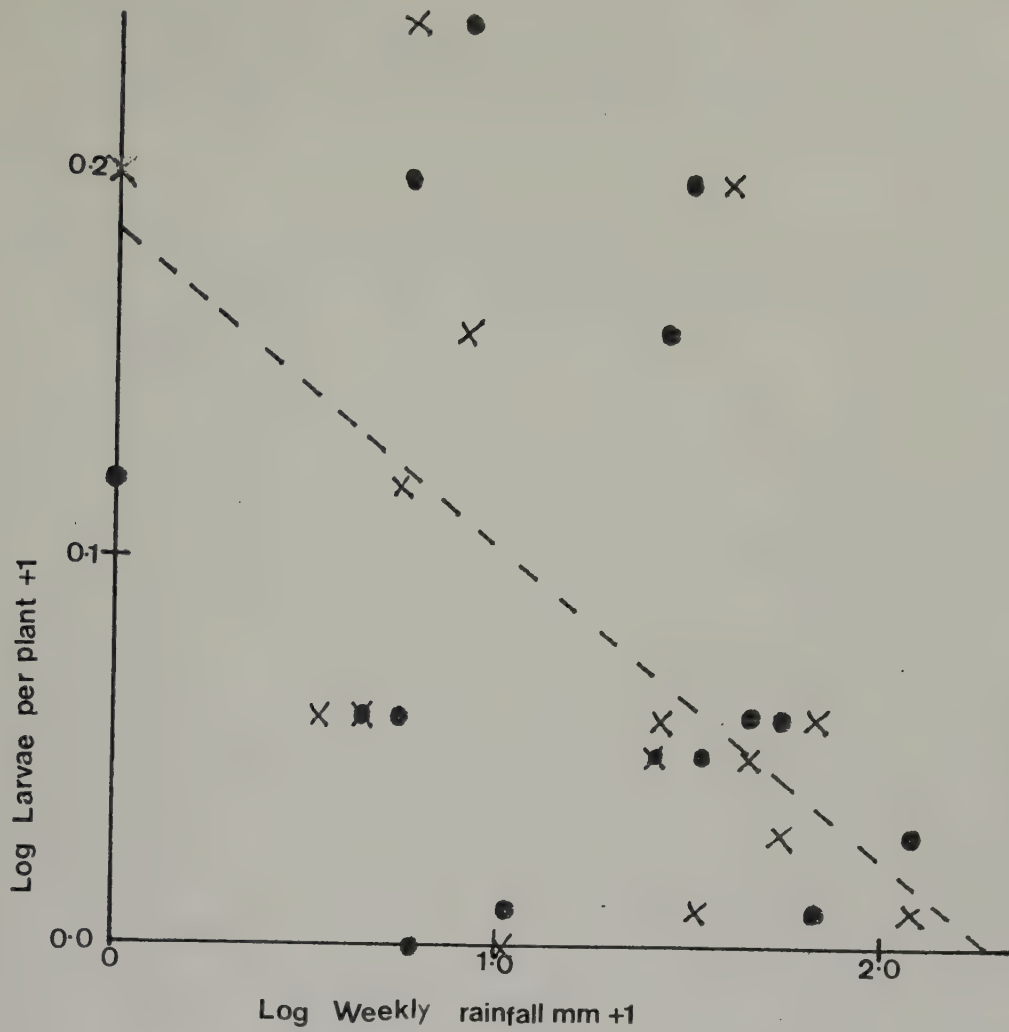
● Amount of rainfall in a week vs the number of larvae per plant in the same week

--- X Amount of rainfall a week earlier vs the number of larvae per plant a week later
 $y = 0.184 - 0.079x$ $r = -0.571^*$, $p = 0.05$, $df = 13$

Figure 46

— ii continued

b- Amount of rainfall in relation to larval population per plant



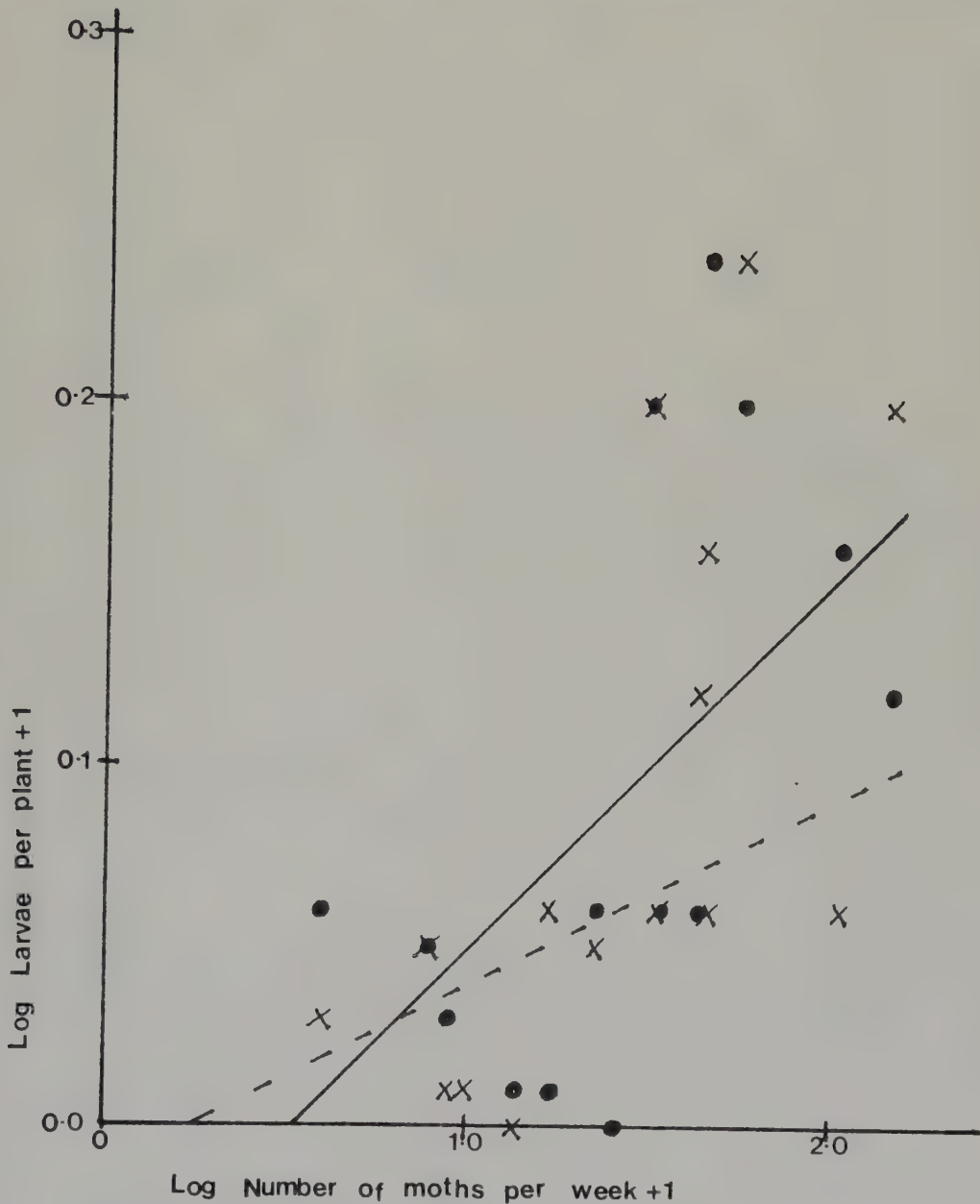
● Amount of rainfall in a week vs the number of larvae per plant in the same week

--- X Amount of rainfall a week earlier vs the number of larvae per plant a week later
 $y = 0.184 - 0.079x$ $r = -0.571^*$, $p = 0.05$, $df = 13$

Figure 46 continued

- iii- The relationship between *H. armigera* male moth catches in a pheromone trap and the level of infestation and damage to cotton at Ukiriguru in 1982-83 season.

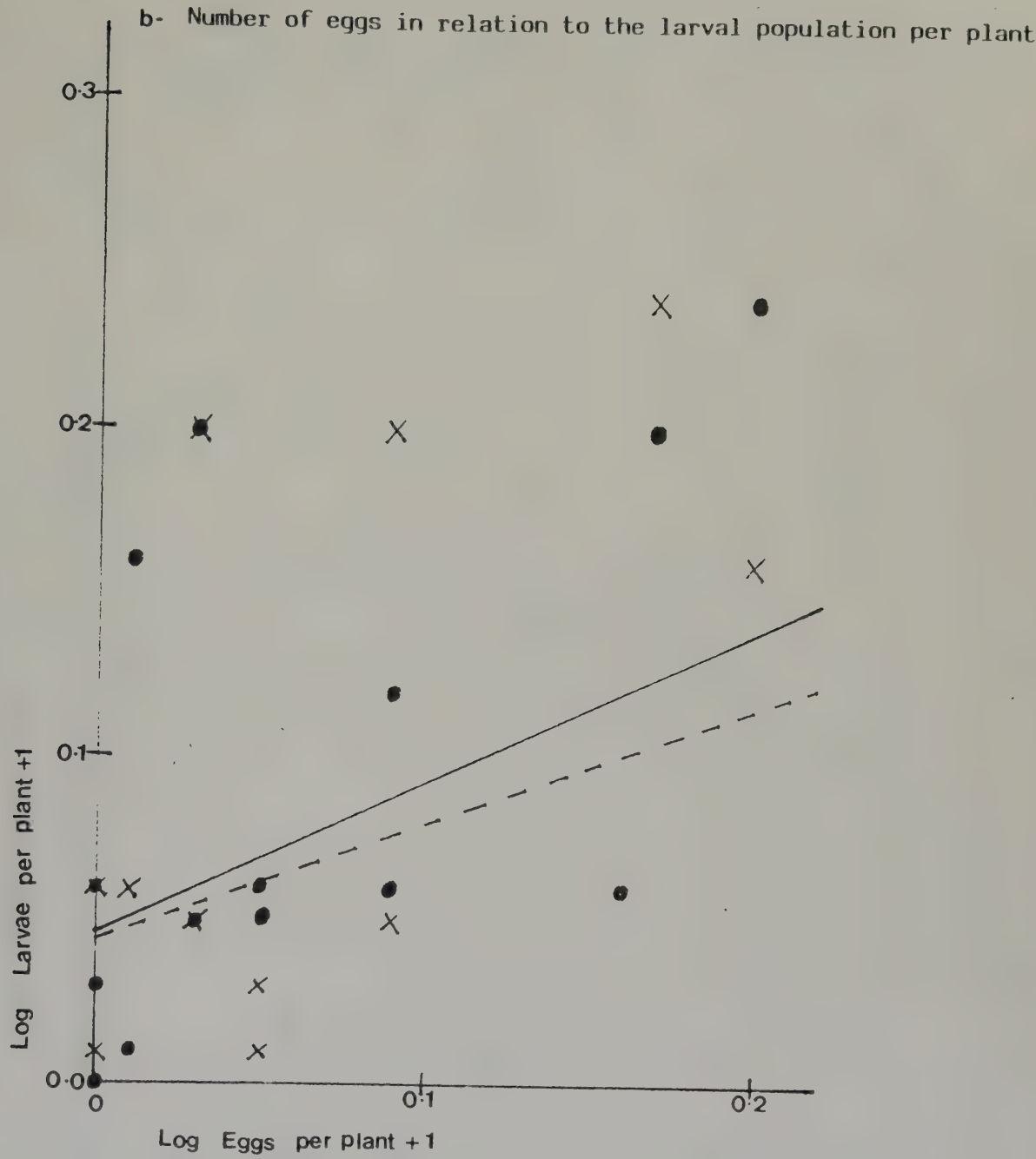
a- Number of moths caught per week in relation to the larval population



- ● Moths per week vs larvae per plant in the same week
 $y = -0.054 + 0.102x$, $r = +0.568^*$, $p = 0.05$, $df = 13$
- X Moths per week vs larvae per plant a week later
 $y = -0.013 + 0.051x$, $r = +0.651^{**}$, $p = 0.01$, $df = 13$

Figure 46

—iii continued

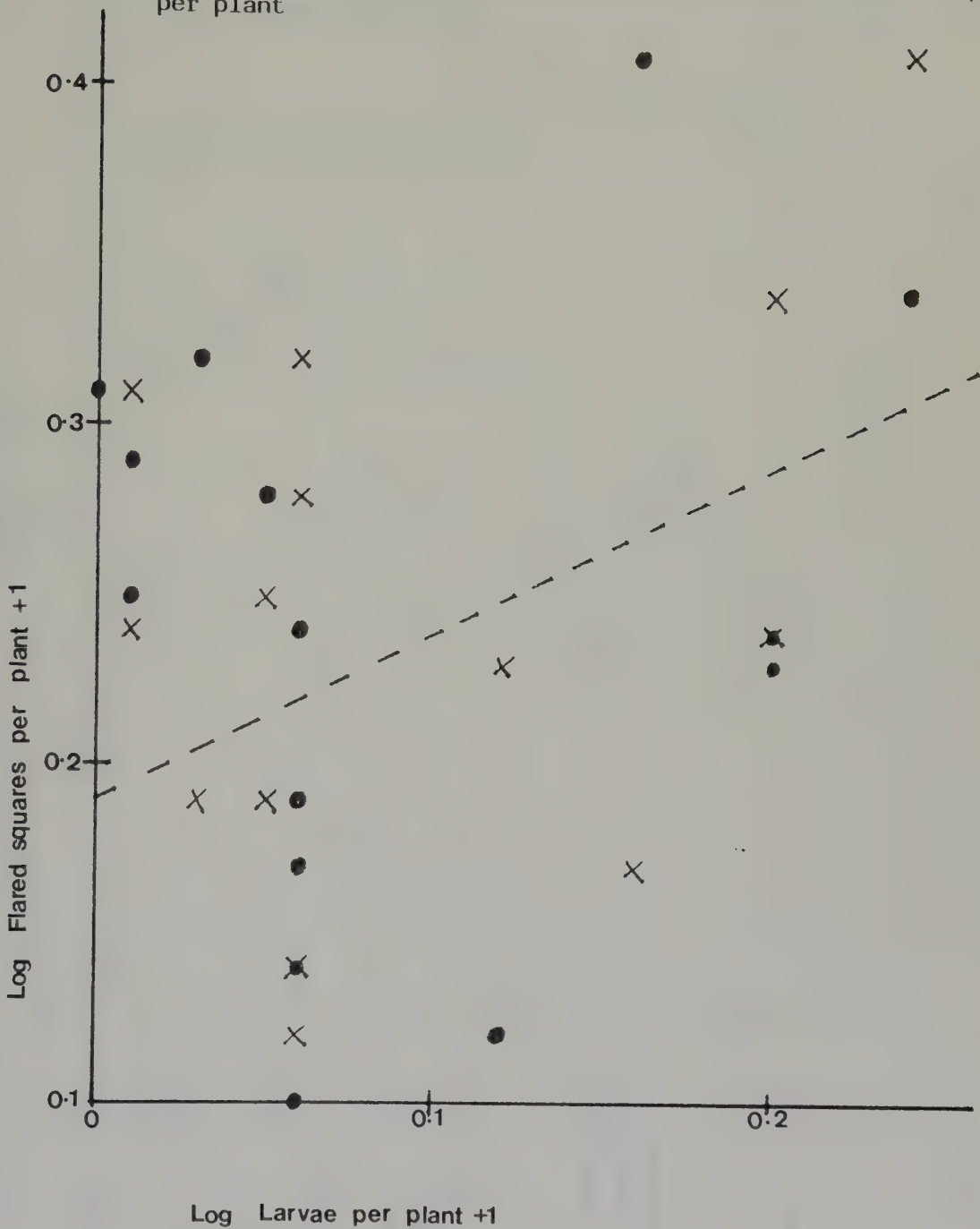


- ● Eggs per plant vs larvae per plant in the same week
 $y = 0.046 + 0.690x$ $r = +0.602^*$, $p < 0.05$, $df = 13$
- - - X Eggs per plant vs larvae per plant a week later
 $y = 0.044 + 0.617x$ $r = +0.558^*$, $p = 0.05$, $df = 13$

Figure 46

— iii continued

c- Larval population in relation to the level of damage (flared squares) per plant



● Larvae per plant vs flared squares per plant in the same week

— — X Larvae per plant vs flared squares per plant a week later
 $y = 0.190 + 0.419x$ $r = +0.418$ n.s., at $p = 0.05$, $df = 13$.

Fig 47 The pattern of *H. armigera* level of infestation and damage on cotton and adult male moth catches in a pheromone trap at Mabuki 1982-83 season.

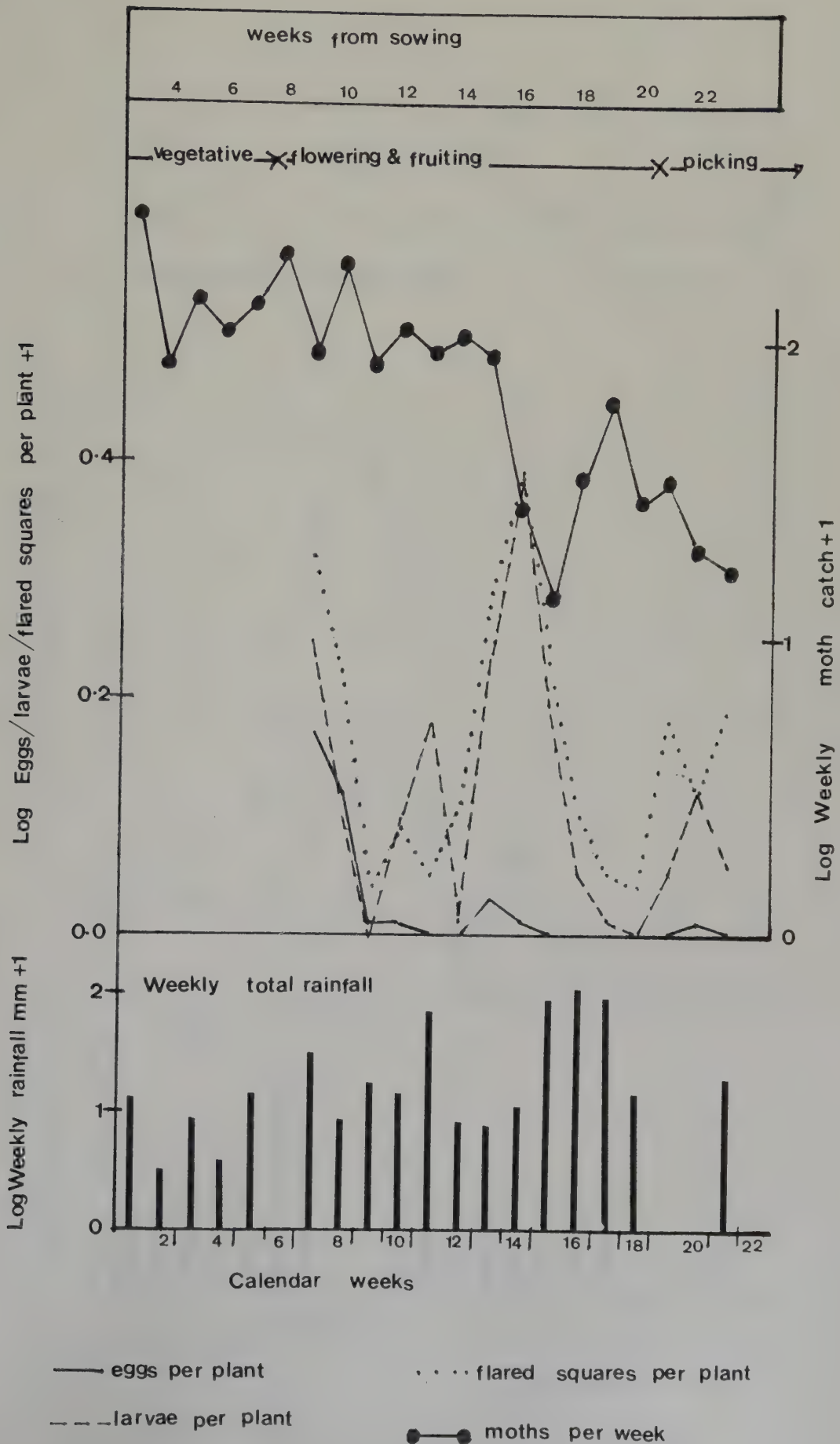


Fig 48

- i- The pattern of *H. armigera* level of infestation and damage on cotton and adult male moth catches in a pheromone trap at Lubaga 1982-83 season.

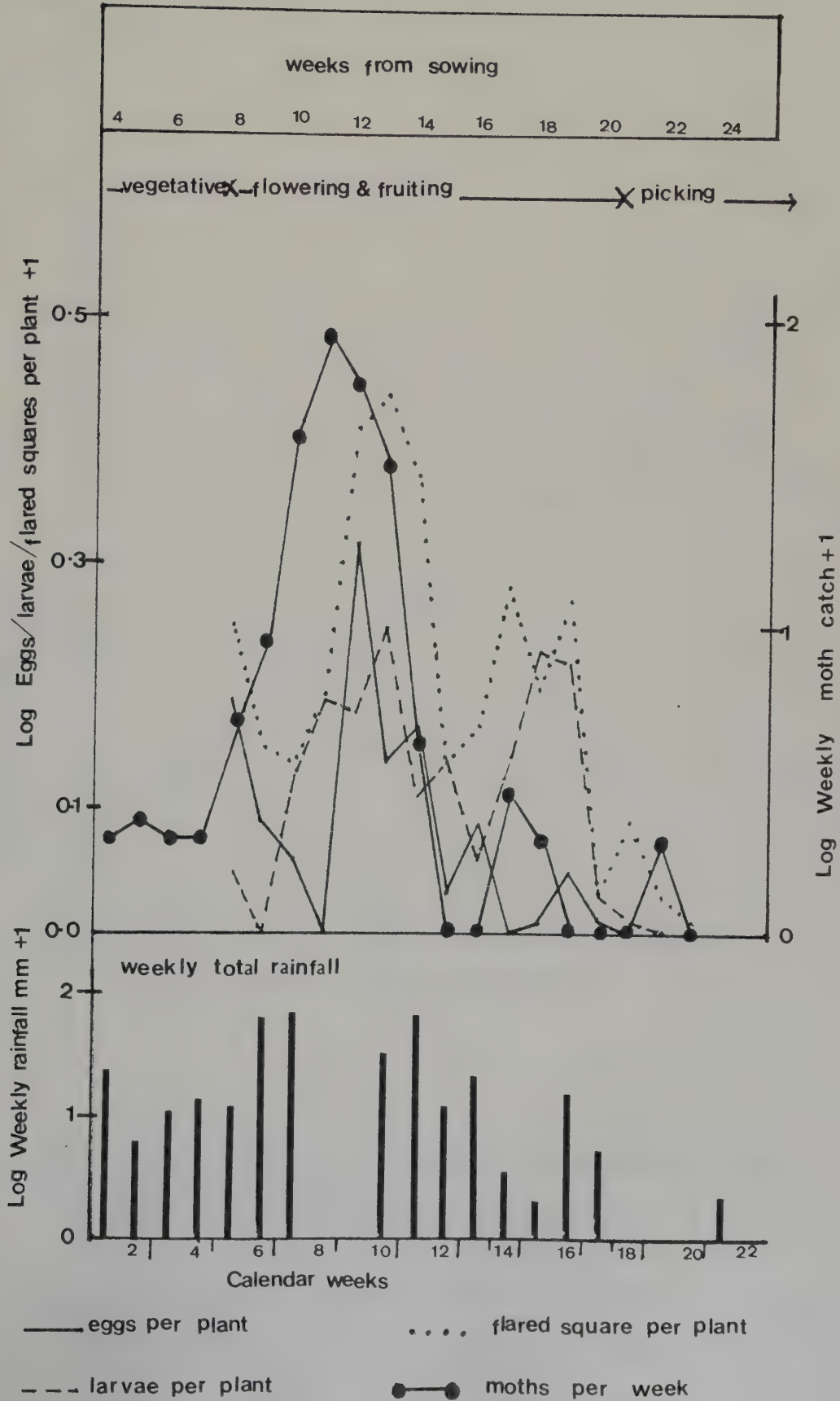
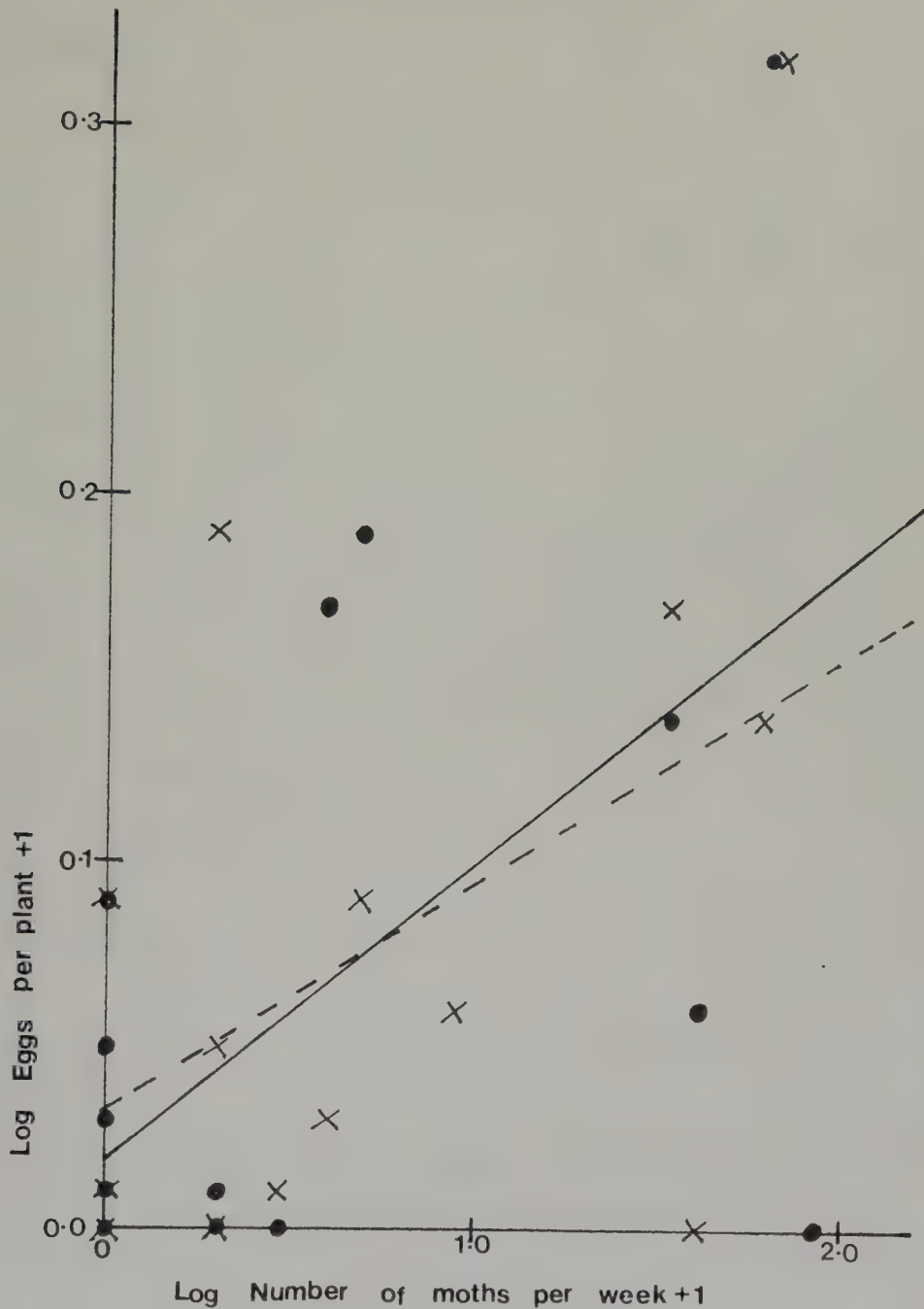


Figure 48 continued

- ii- The relationship between *H. armigera* level of infestation and damage and the number of male moths caught in the pheromone trap.
- a- The relationship between the weekly number of moths caught and the level of infestation and damage



- ● Number of moths caught per week vs the number of eggs per plant within the same week
 $y = 0.032 + 0.062x$, $r = +0.478$ n.s. at $p = 0.05$, $df = 14$
- X Number of moths caught per week vs the number of eggs per plant a week later
 $y = 0.0197 + 0.081x$ $r = +0.611^*$, $p = 0.05$, $df = 14$

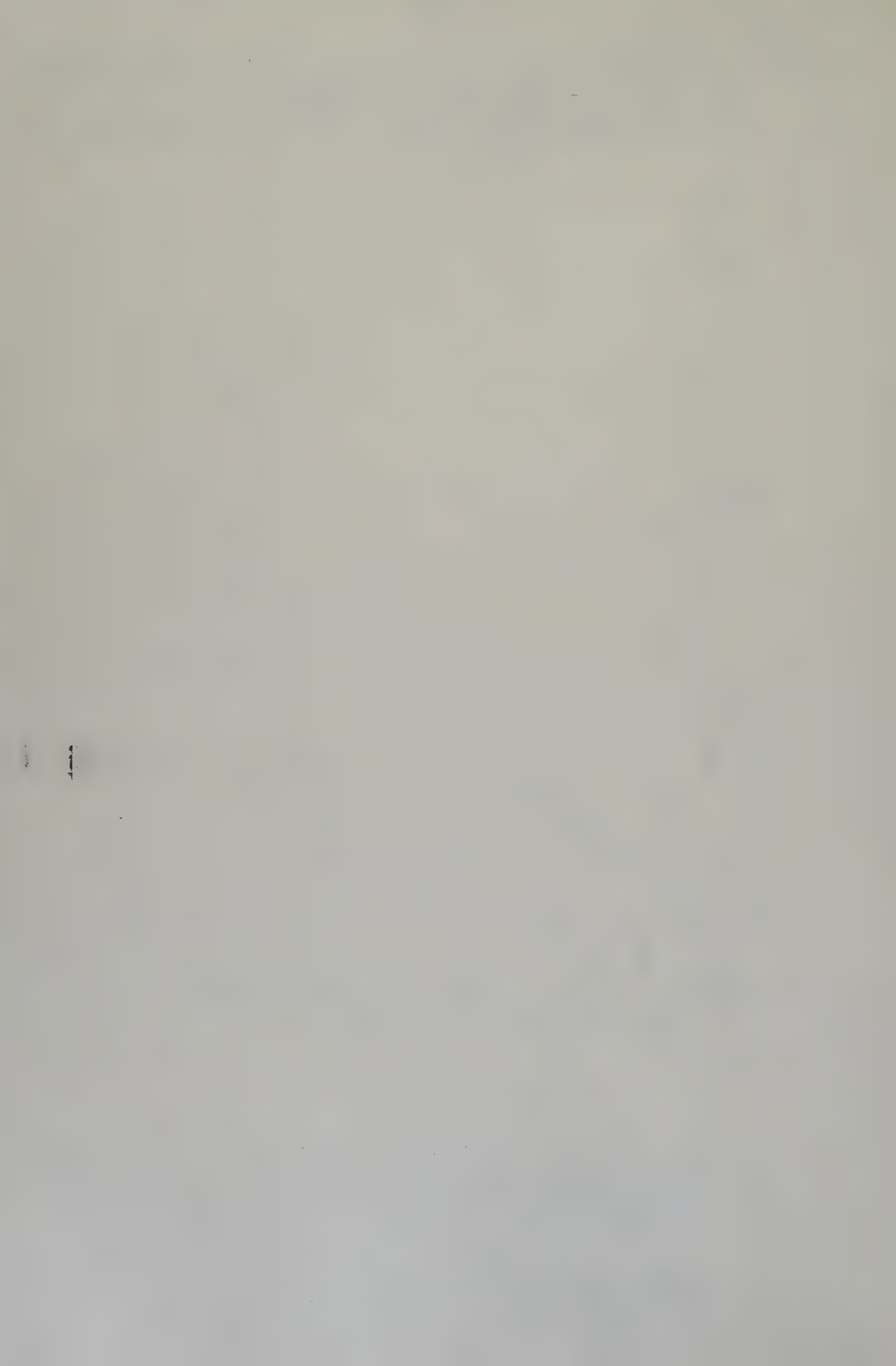
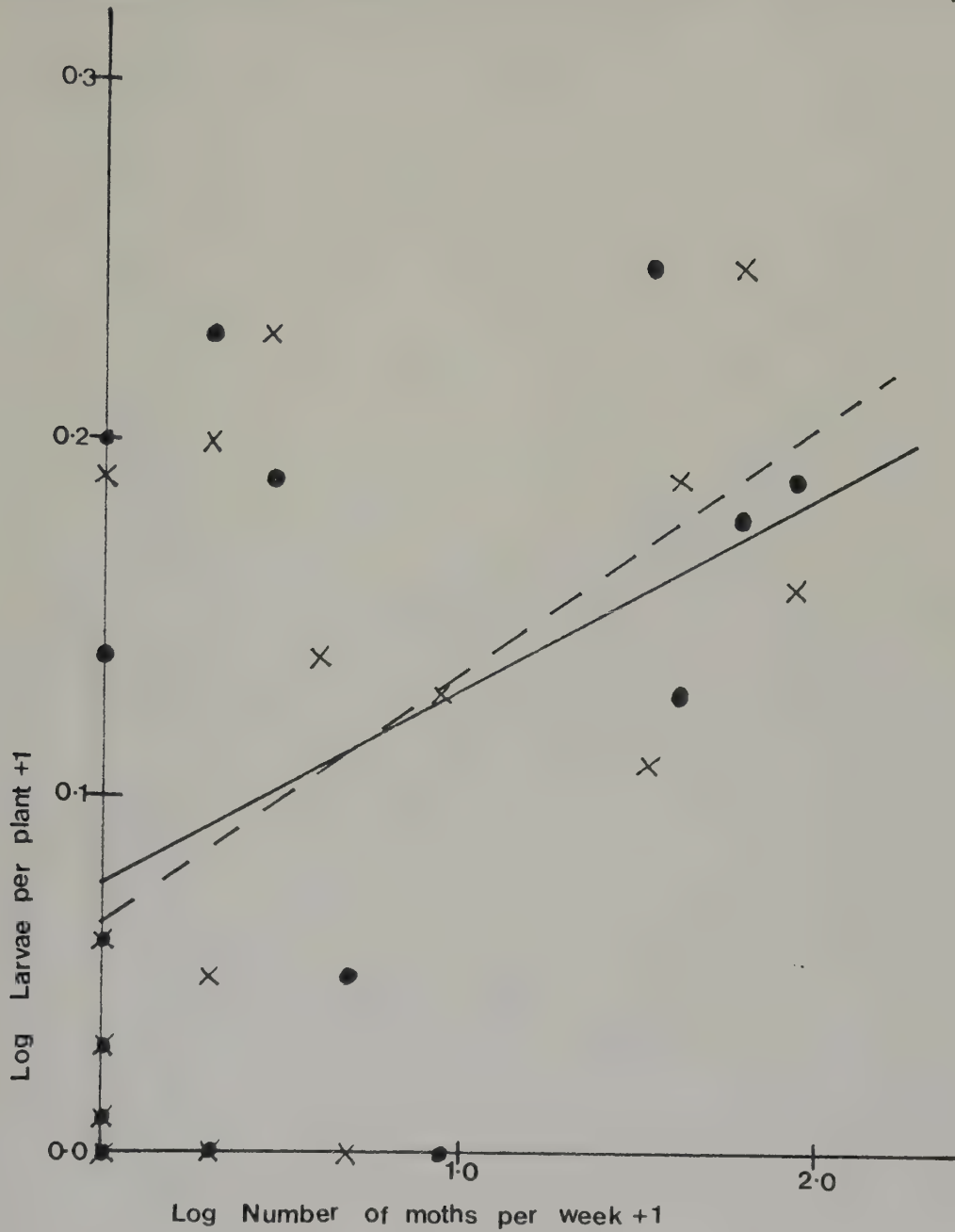


Figure 48- ii continued

b. Number of moths caught per week in relation to the larval population

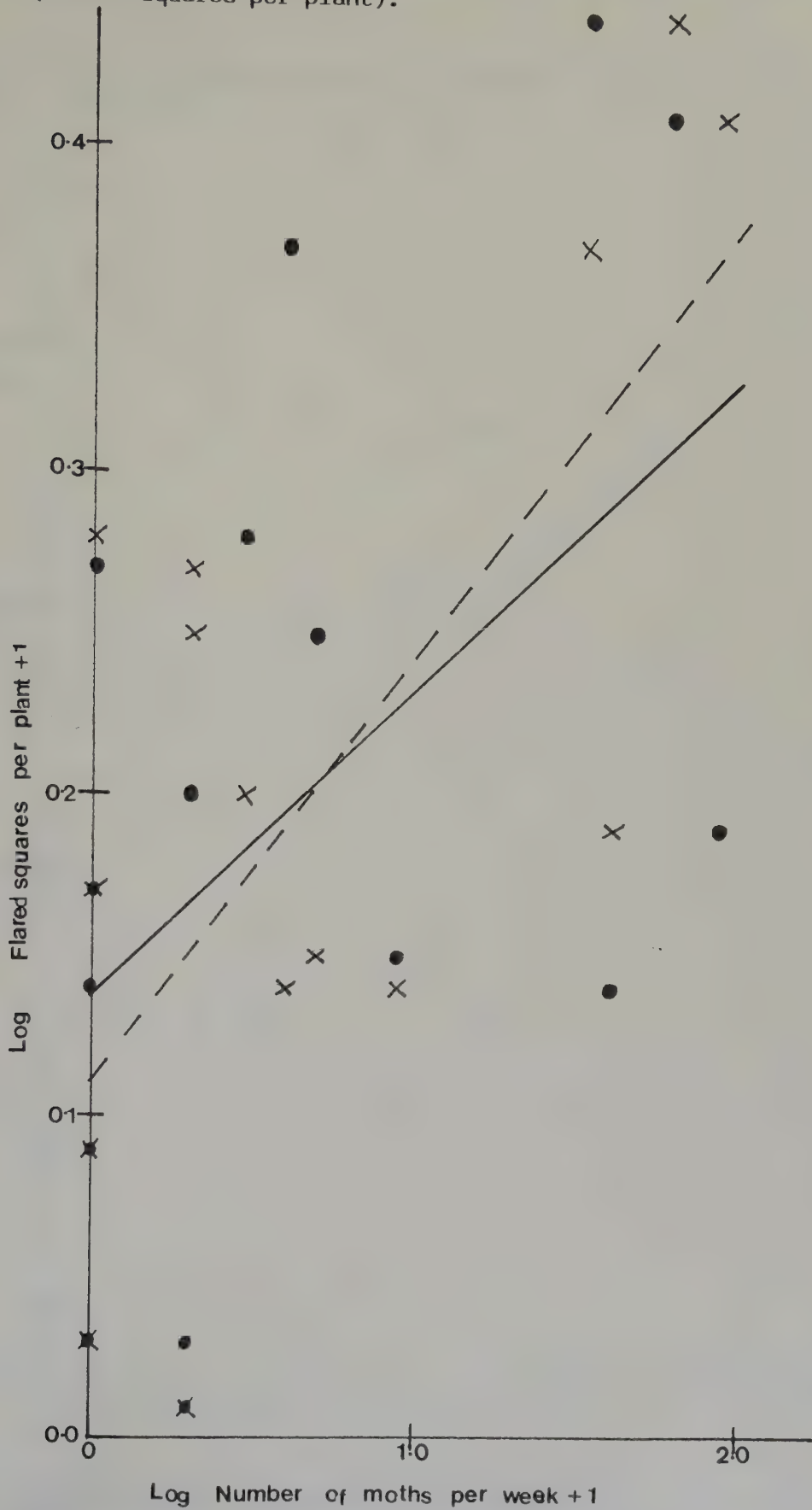


— ● Number of moths caught per week vs number of larvae per plant within the same week
 $y = 0.076 + 0.055x$ $r = +0.436$ n.s. at $p = 0.05$, $df = 14$

--- X Number of moths caught per week vs number of larvae per plant a week later
 $y = 0.065x + 0.069x$ $r = +0.538^*$, $p = 0.05$, $df = 14$

Figure 48 - ii continued

c- Number of moths caught per week in relation to the level of damage (flared squares per plant).

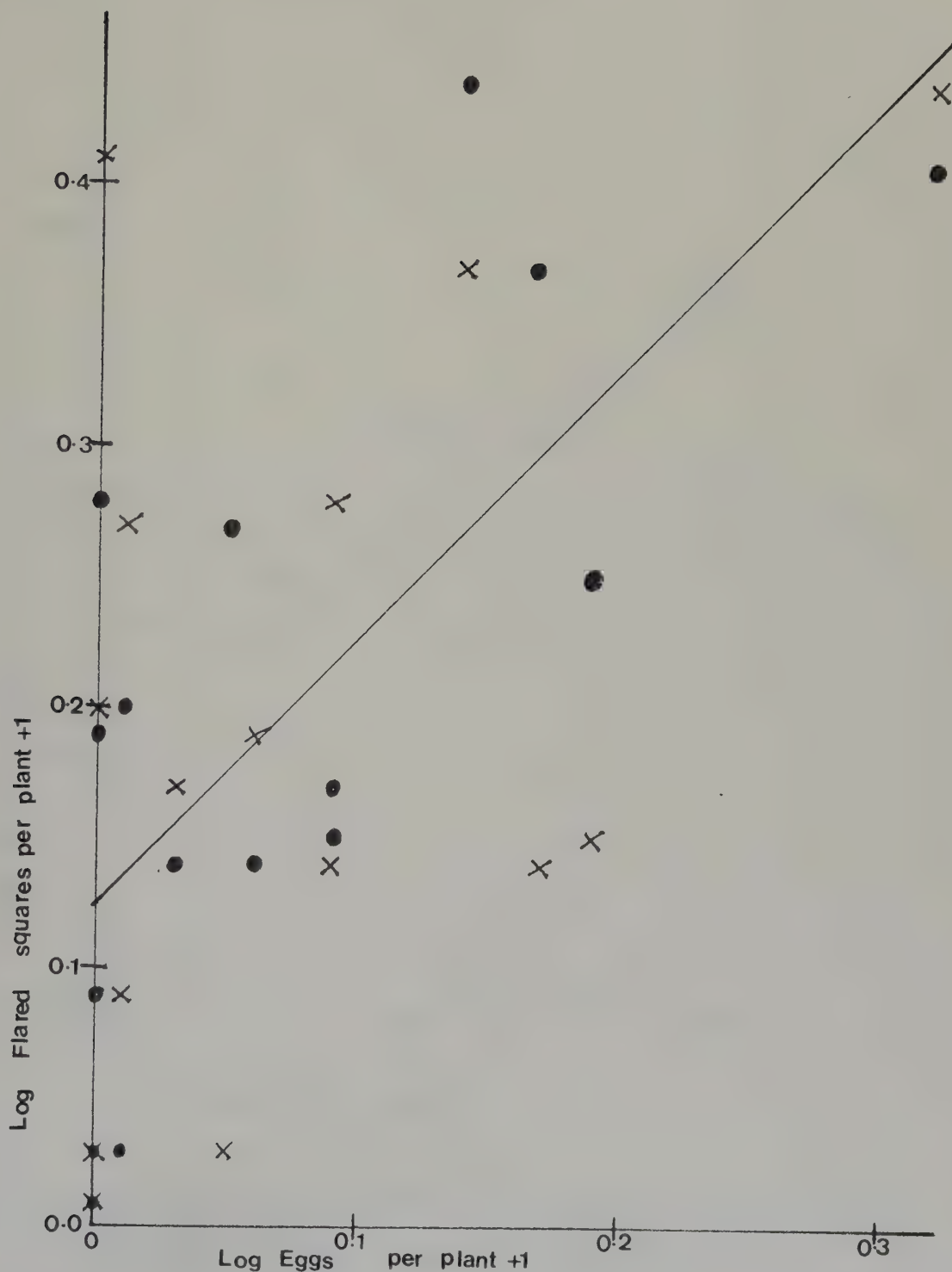


— ● Number of moths caught per week vs flared squares per plant within the same week
 $y = 0.137 + 0.095x$, $r = +0.504^*$, $p = 0.05$, $df = 14$

- - - X Number of moths caught per week vs flared squares per plant a week later
 $y = 0.112 + 0.131x$, $r = +0.691^{***}$, $p = 0.005$, $df = 14$

Figure 48 continued —iii The relationship between the level of infestation and damage to cotton.

- a. Level of eggs per plant in relation to the level of flared squares per plant.



— ● Eggs per plant vs number of flared squares per plant within the same week.

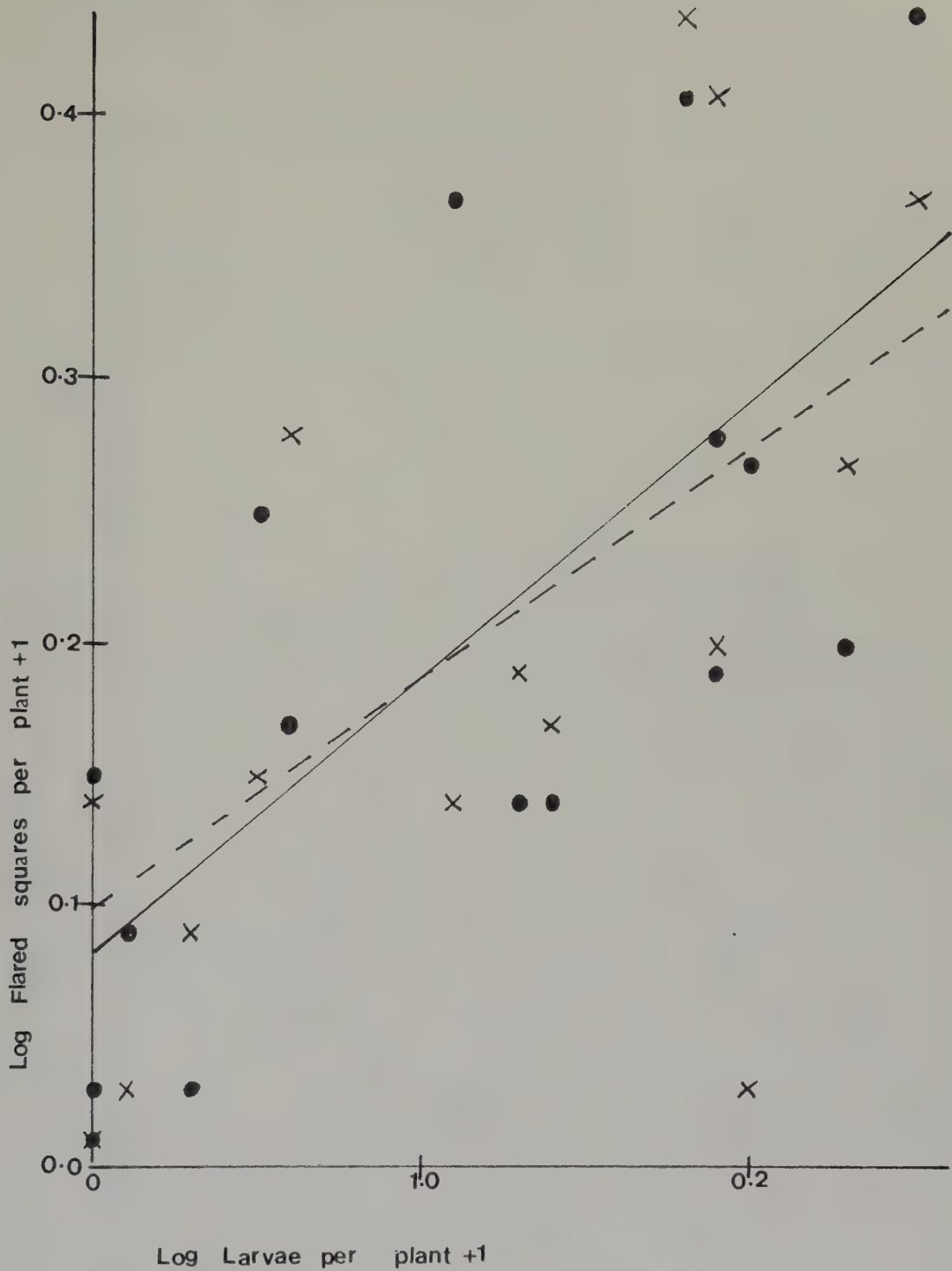
$$y = 0.123 + 1.03x, r = +0.719^{***}, p = 0.005, df = 14$$

X Eggs per plant vs number of flared squares per plant a week later

$$y = 0.095 + 0.188x, r = +0.453 \text{ n.s. at } p = 0.05, df = 14$$

Figure 48-iii continued

b- Larval population per plant in relation to the level of flared squares per plant



— ● Larvae per plant vs number of flared squares per plant within the same week
 $y = 0.082 + 1.05x$ $r = +0.709^{***}$, $p < 0.005$, $df = 14$

- - - X Larvae per plant vs number of flared squares per plant a week later
 $y = 0.097 + 0.889x$ $r = +0.580^*$, $p = 0.05$, $df = 14$

Fig 49 The pattern of *H. armigera* level of infestation and damage on cotton and adult male moth catches in a pheromone trap at Mwanhala in 1982-83

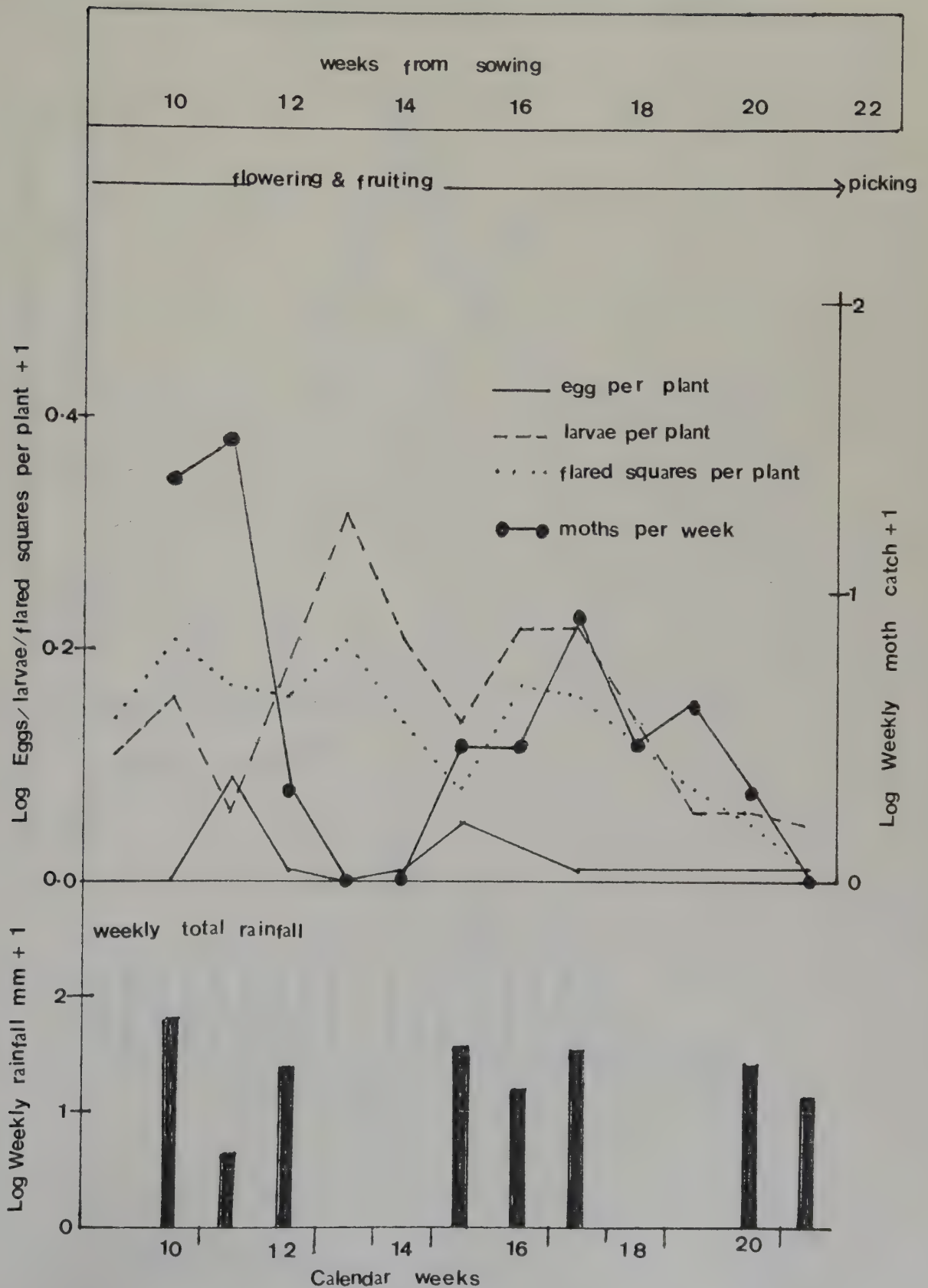


Fig 50

- i- The pattern of *H. armigera* level of infestation and damage on cotton and adult male moth catches in a pheromone trap at Ukiriguru 1983-84 season.

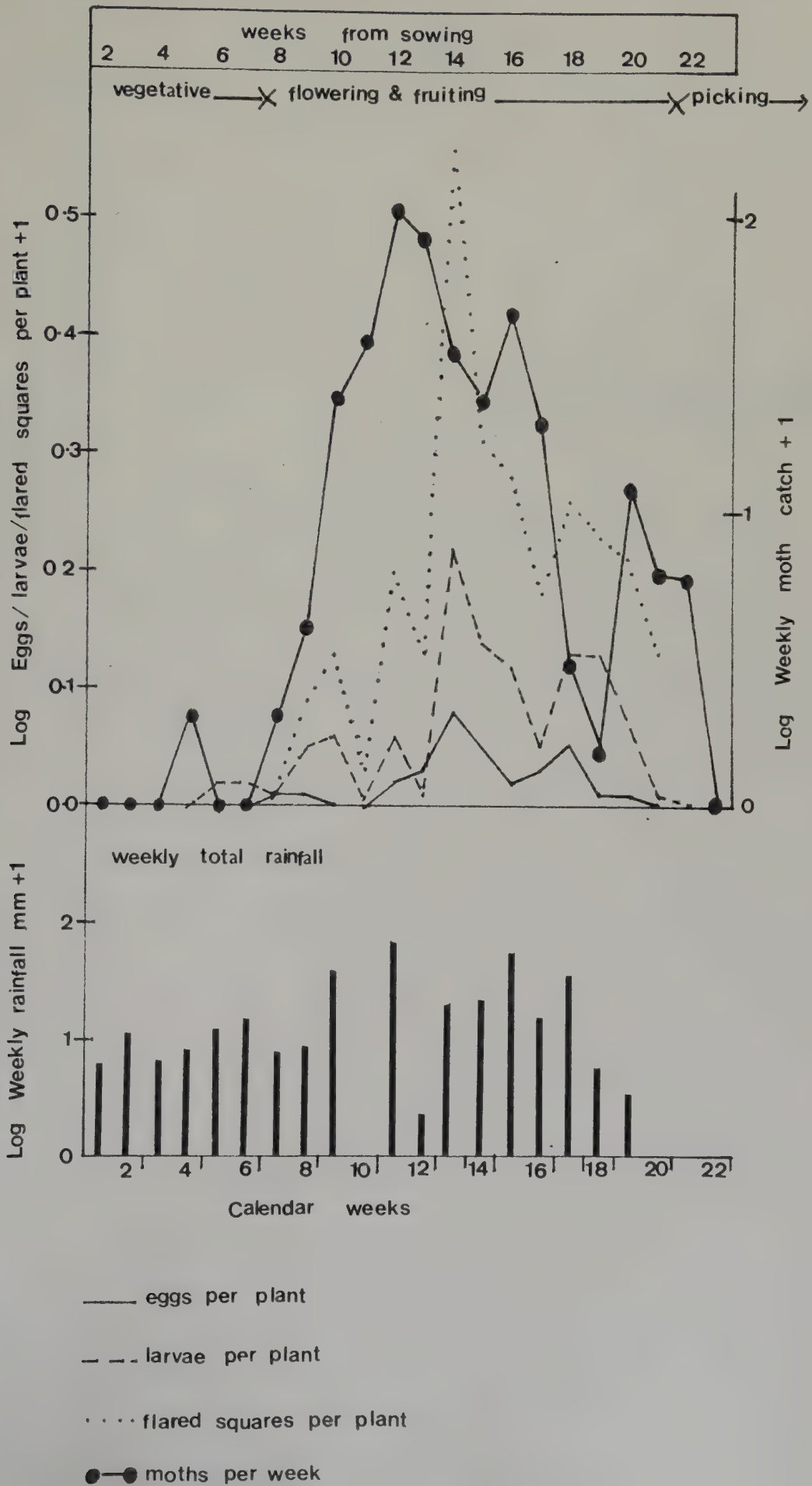


Figure 50 continued

- ii- The relationship between the weekly amount of rainfall and the larval population at Ukiriguru 1983-84.

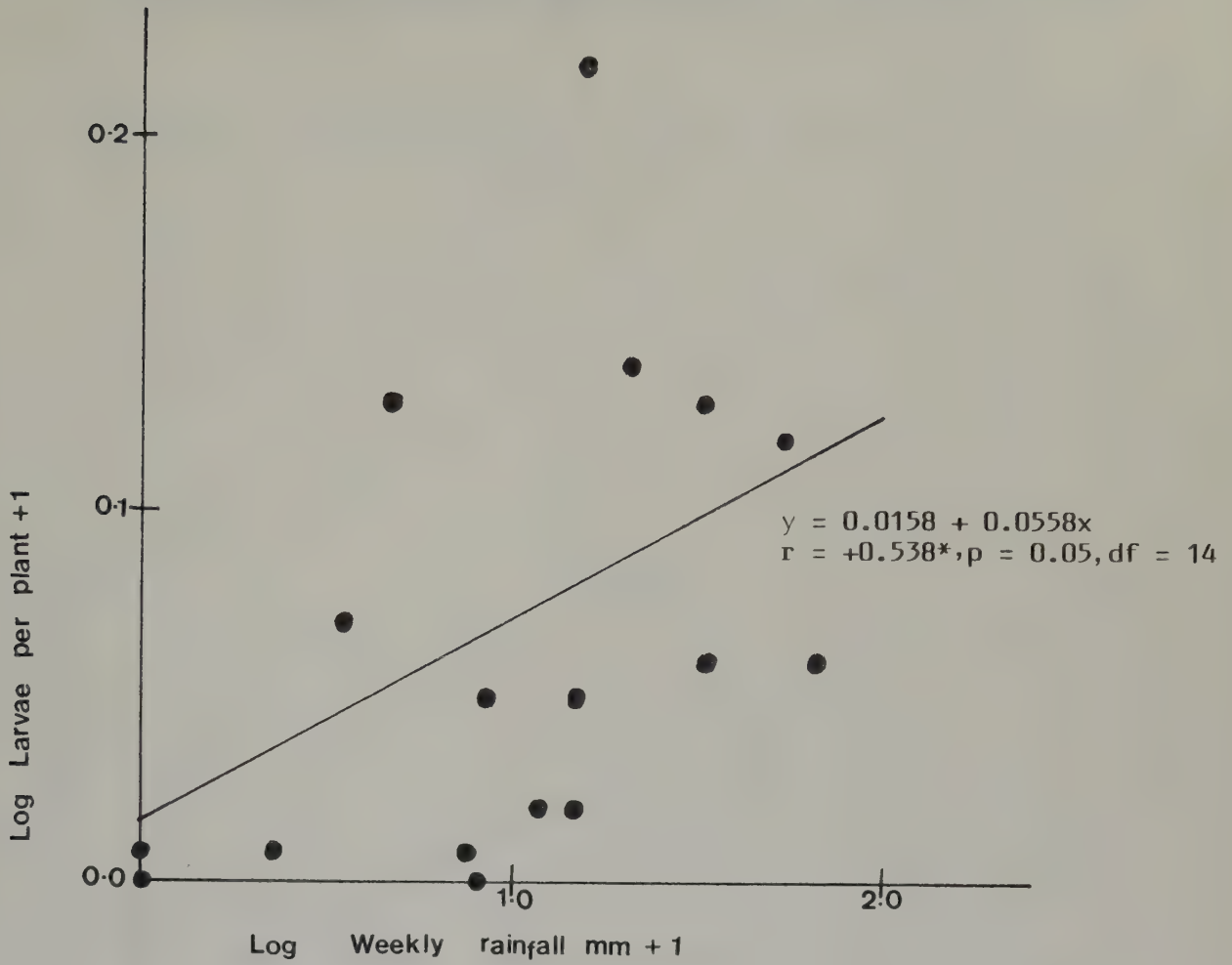
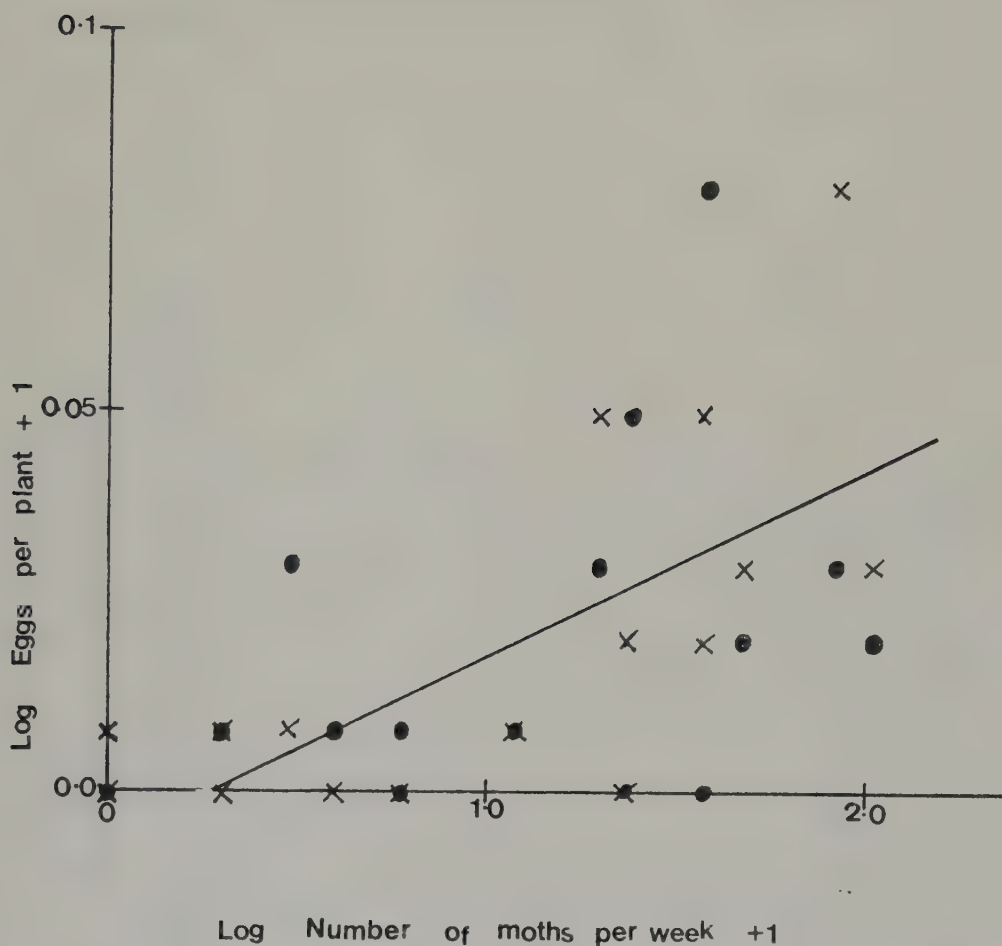


Figure 50 continued

- iii- The relationship between H. armigera level of infestation and damage to cotton and the number of male moths caught in the pheromone trap

a- Number of moths caught in relation to the number of eggs per plant.

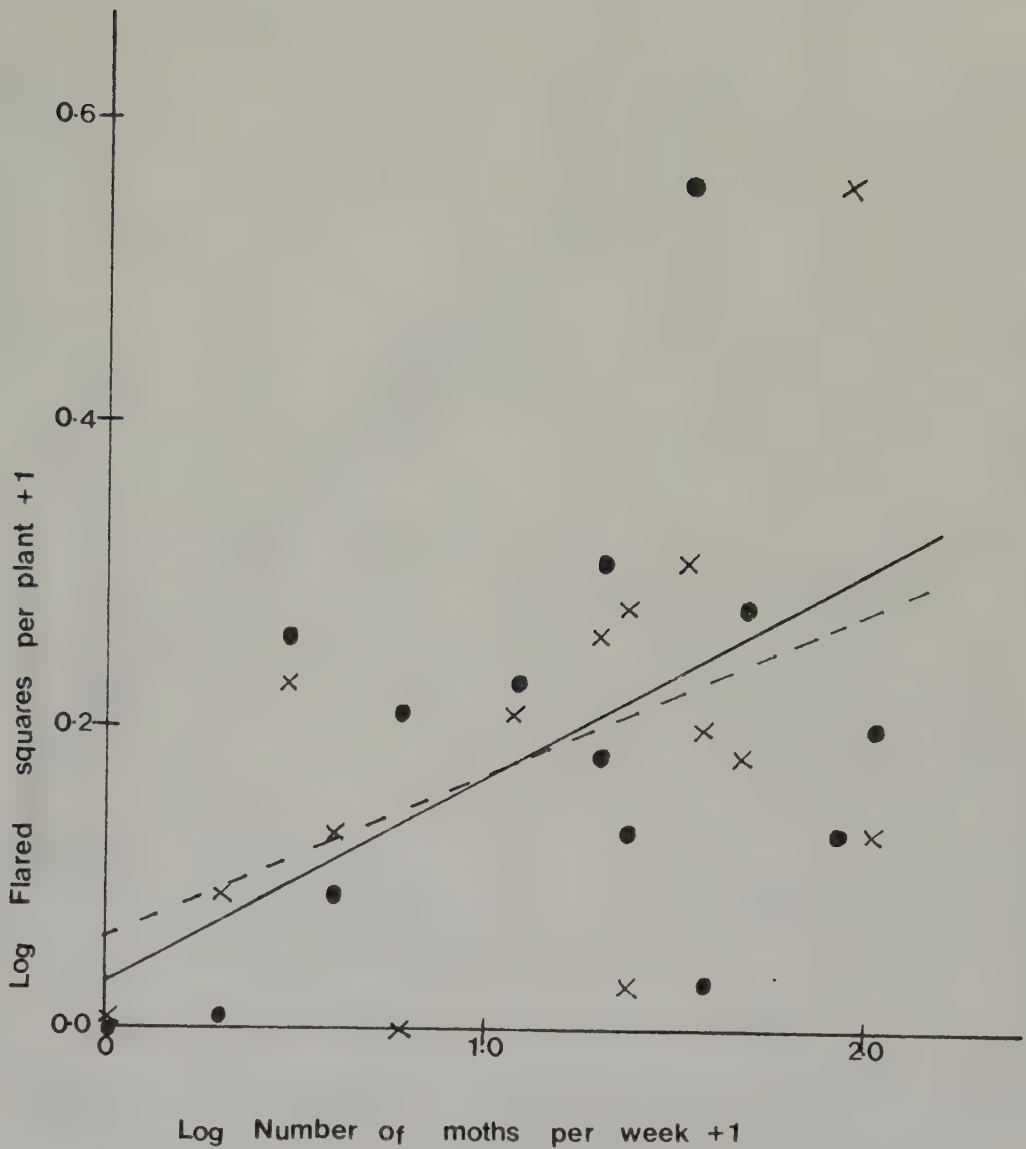


● Number of moths vs number of eggs per plant within the same week.
 $y = 0.008 + 0.011x$ $r = +0.355$ n.s. at $p = 0.05$, $df = 14$

— X Number of moths vs number of eggs per plant a week later.
 $y = -0.006 + 0.024x$ $r = +0.672^{***}$, $p = 0.005$, $df = 14$.

Figure 50—iii continued

b- Number of moths caught per week in relation to the level of damage (flared squares per plant)



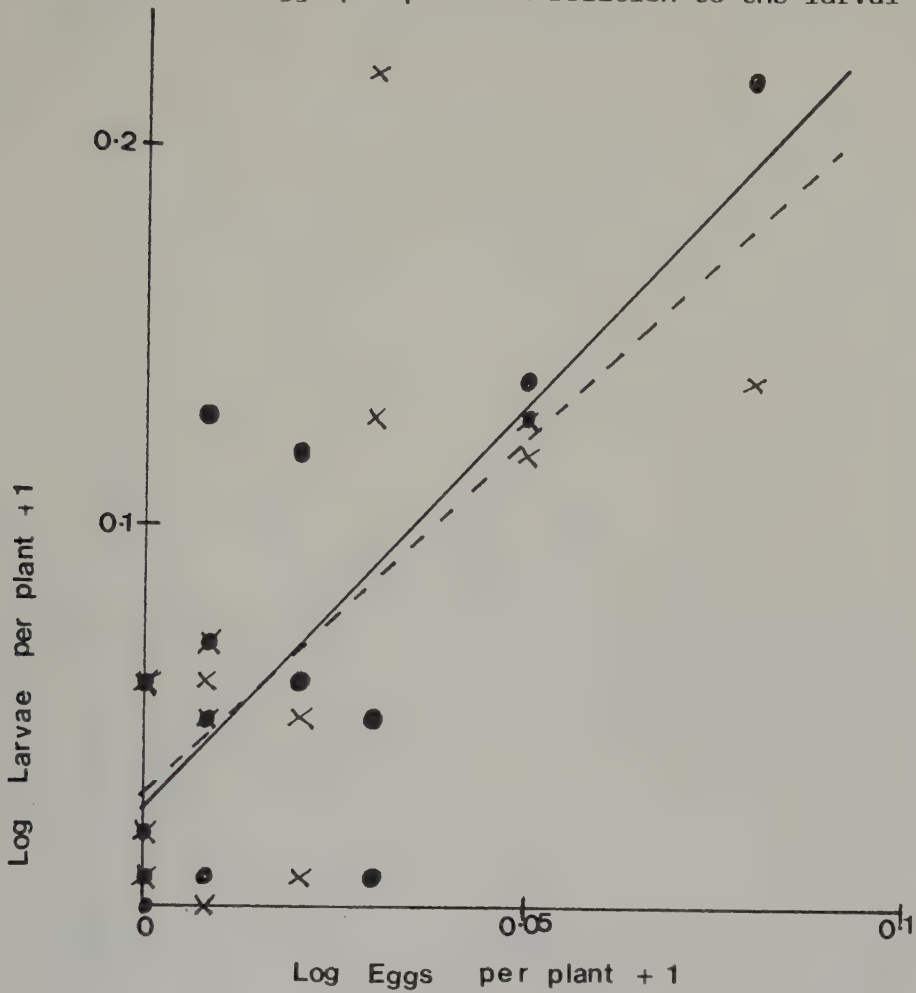
--- ● Number of moths vs number of flared squares per plant within the same week
 $y = 0.059 + 0.107x$ $r = +0.482$ n.s. at $p = 0.05$, $df = 14$

— X Number of moths vs number of flared squares per plant a week later
 $y = 0.030 + 0.135x$ $r = +0.607^*$, $p = 0.05$, $df = 14$

Figure 50 continued

iv- The relationship between the level of infestation and damage to cotton

a- Level of eggs per plant in relation to the larval population.



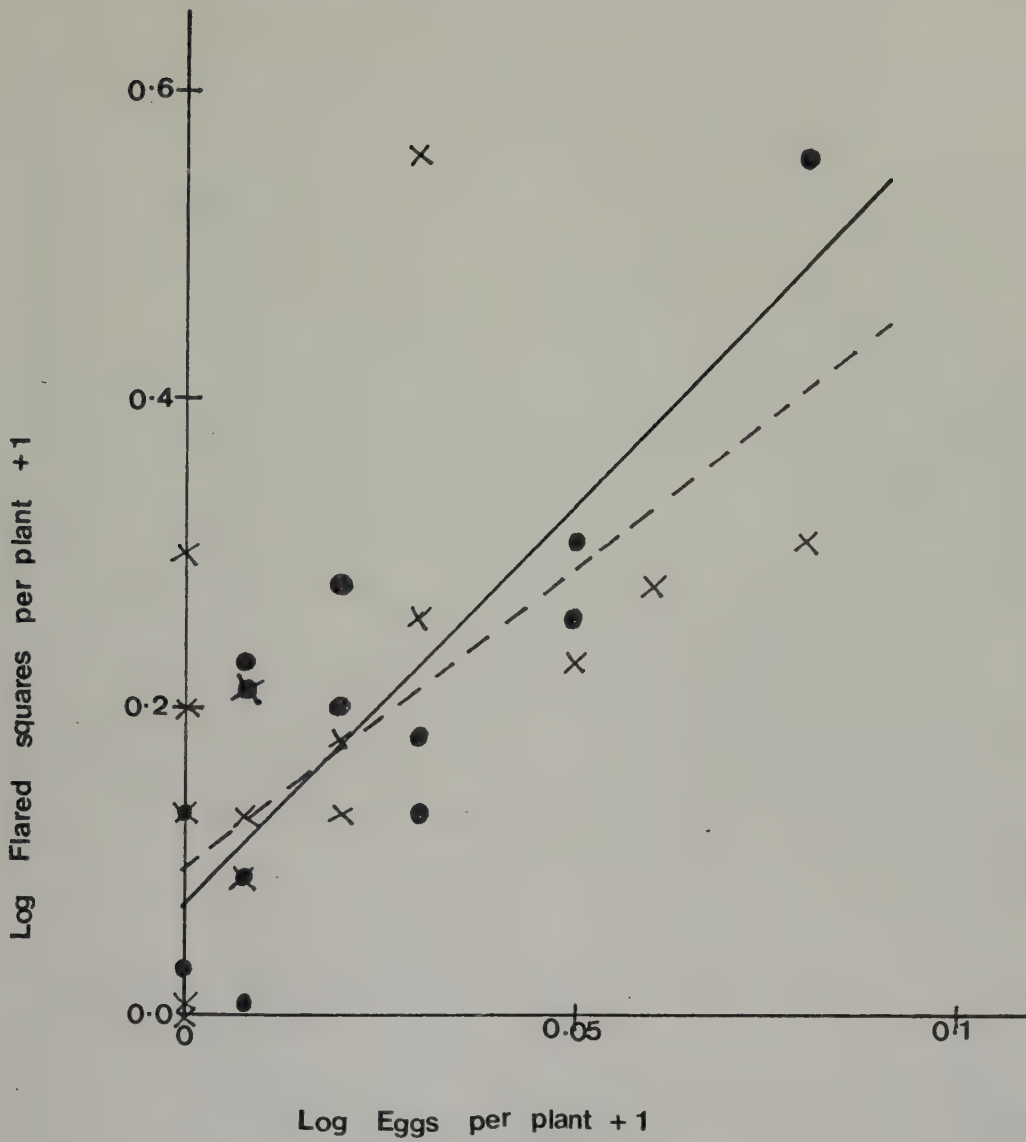
— ● Number of eggs per plant vs number of larvae per plant within the same week
 $y = 0.026 + 2.13x$ $r = +0.781^{****}$, $p < 0.001$, $df = 14$

- - - X Number of eggs per plant vs number of larvae per plant a week later
 $y = 0.030 + 1.93x$ $r = +0.707^{***}$, $p = 0.005$, $df = 14$

Handwritten notes or signatures.

Figure 50 — iv continued

b- Number of eggs per plant in relation to the level of damage (flared squares per plant).

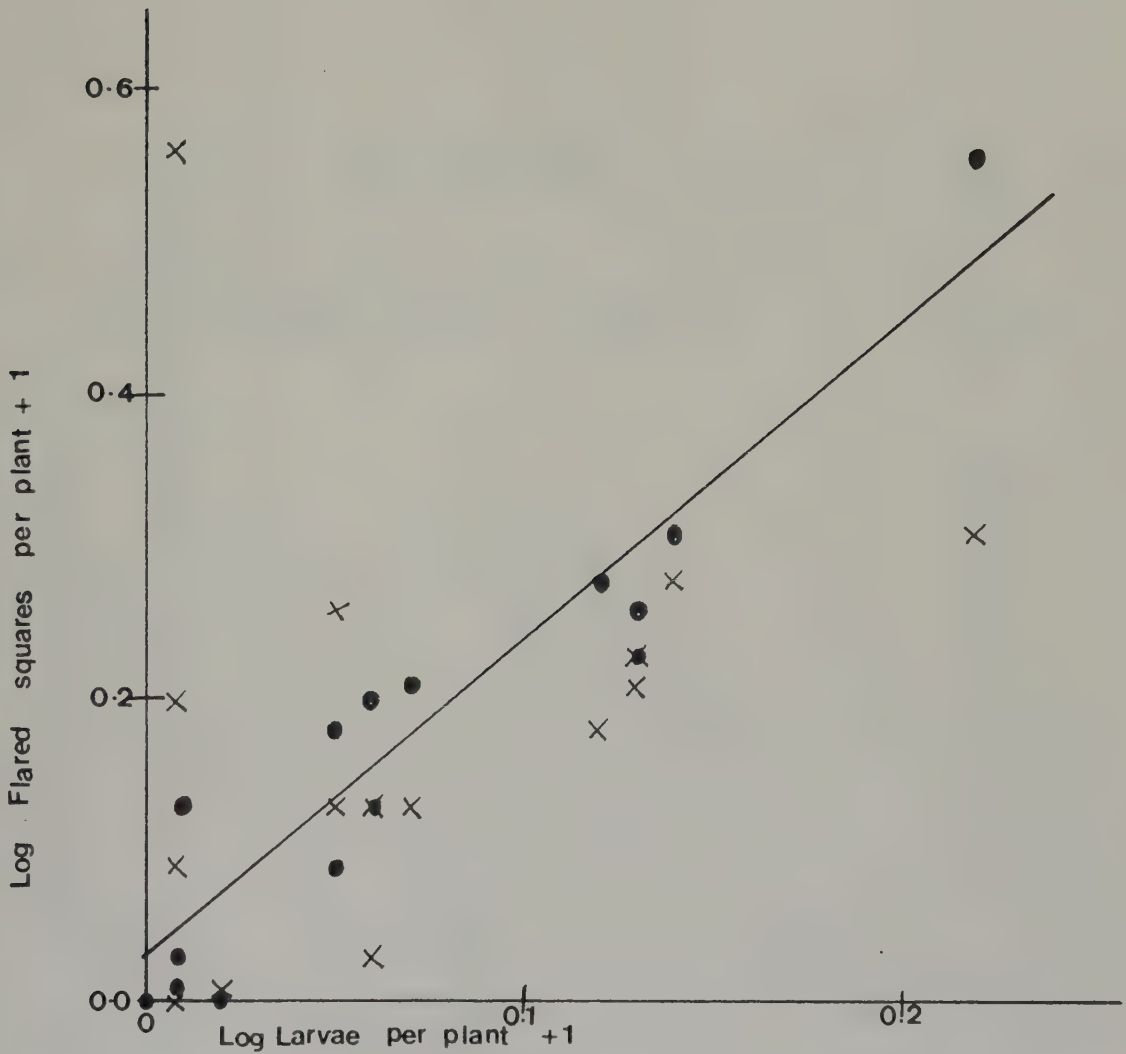


— ● Number of eggs per plant vs number of flared squares per plant within the same week
 $y = 0.069 + 5.25x$ $r = +0.849^{****}$, $p < 0.001$, $df = 14$

--- x Number of eggs per plant vs number of flared squares per plant a week later
 $y = 0.095 + 3.92x$ $r = +0.633^{**}$, $p = 0.01$, $df = 14$

Figure 50 — iv continued

c- Larval population in relation to the level of damage



● Number of larvae per plant vs number of flared squares per plant within the same week
 $y = 0.029 + 2.11x$ $r = +0.931^{****}$, $p < 0.001$, $df = 14$

X Number of larvae per plant vs number of flared squares per plant a week later
 $y = 0.407 - 1.37x$ $r = -0.179$ n.s. at $p = 0.05$, $df = 14$

Figure 51

i- The pattern of *H. armigera* infestation and damage on cotton and the adult male moth catches in a pheromone trap at Mabuki 1983-84.

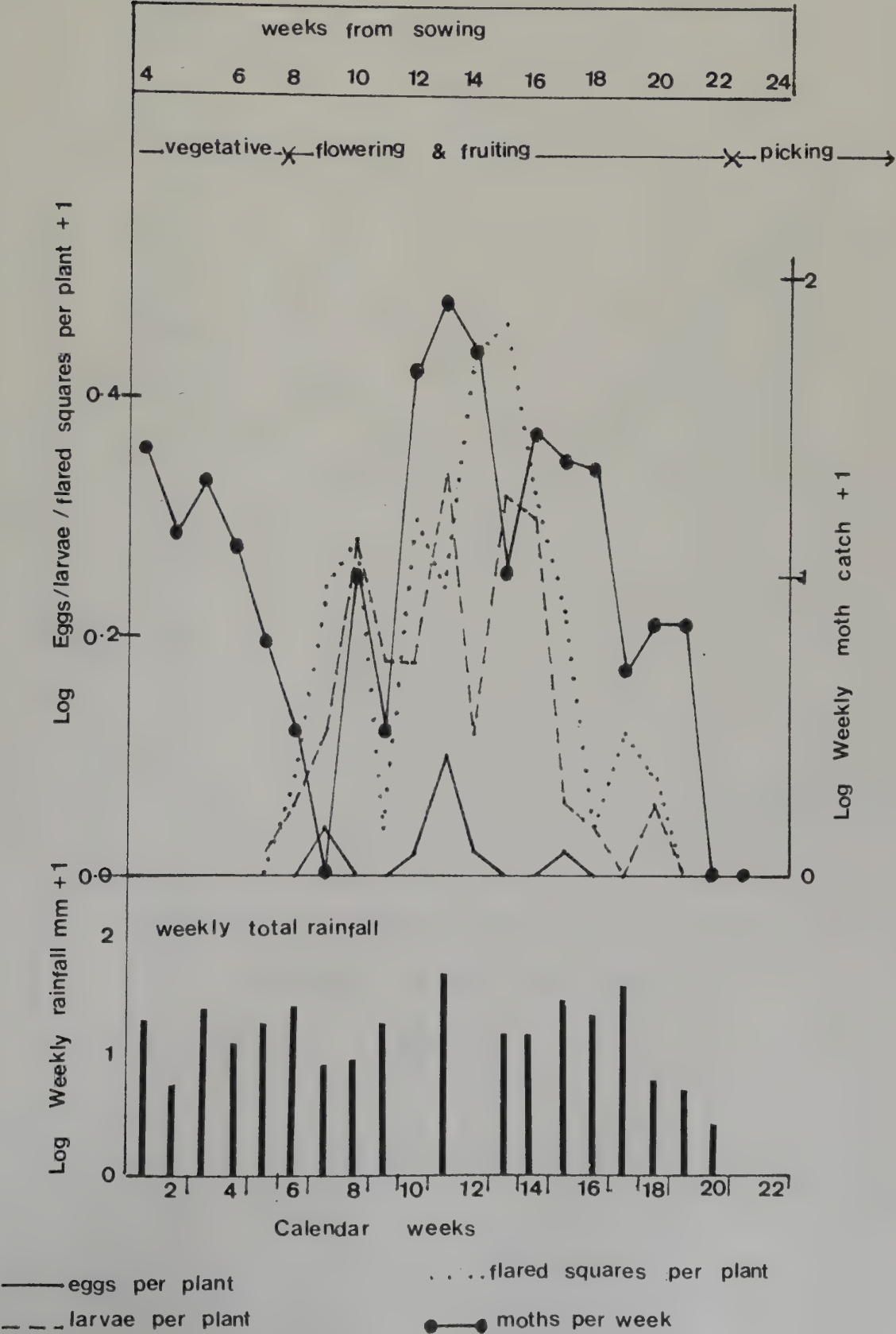


Figure 51 continued

- ii- The relationship between H. armigera level of infestation and damage to cotton and the number of male moths caught in the pheromone trap

a- Number of moths vs the larval population in the same week

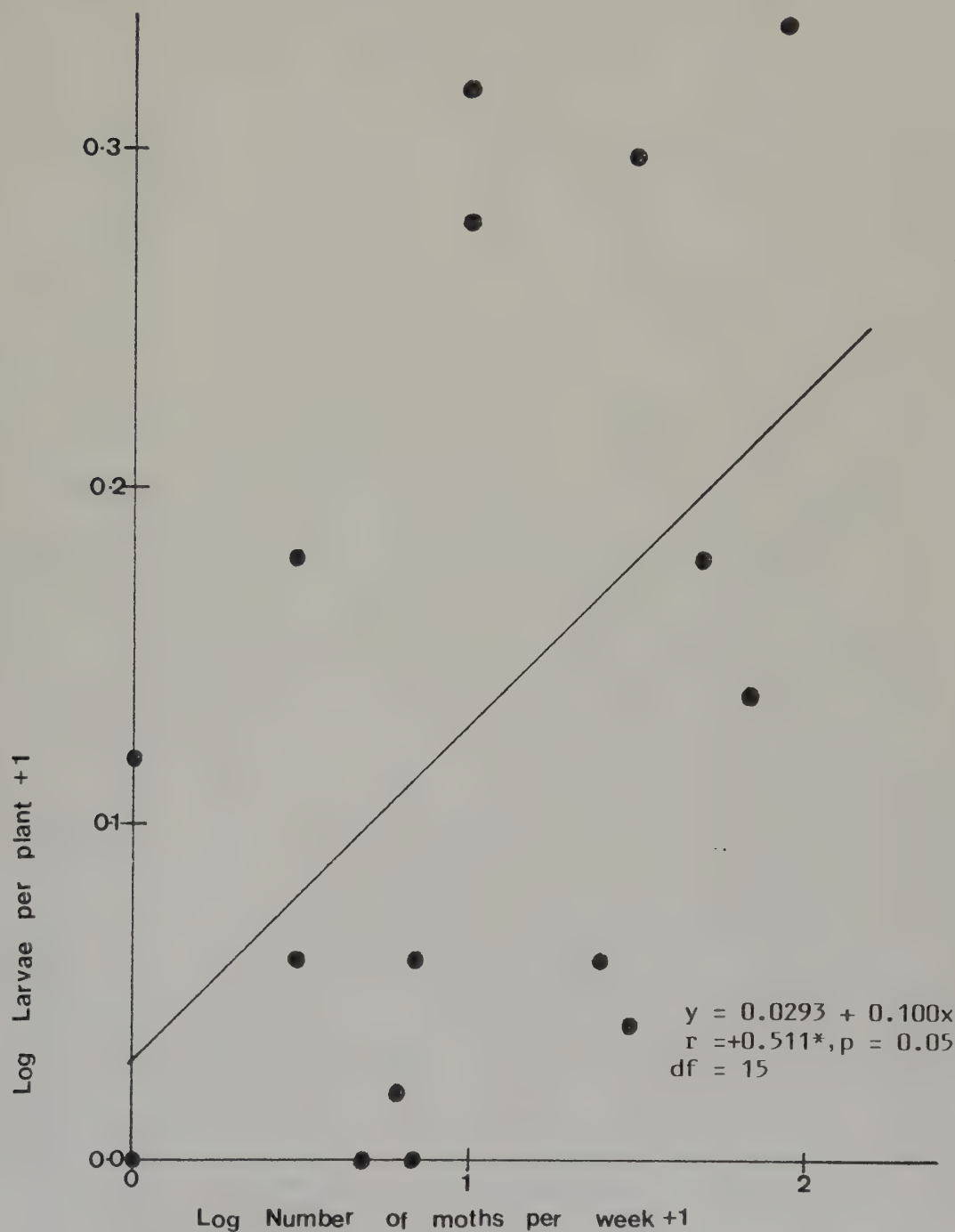
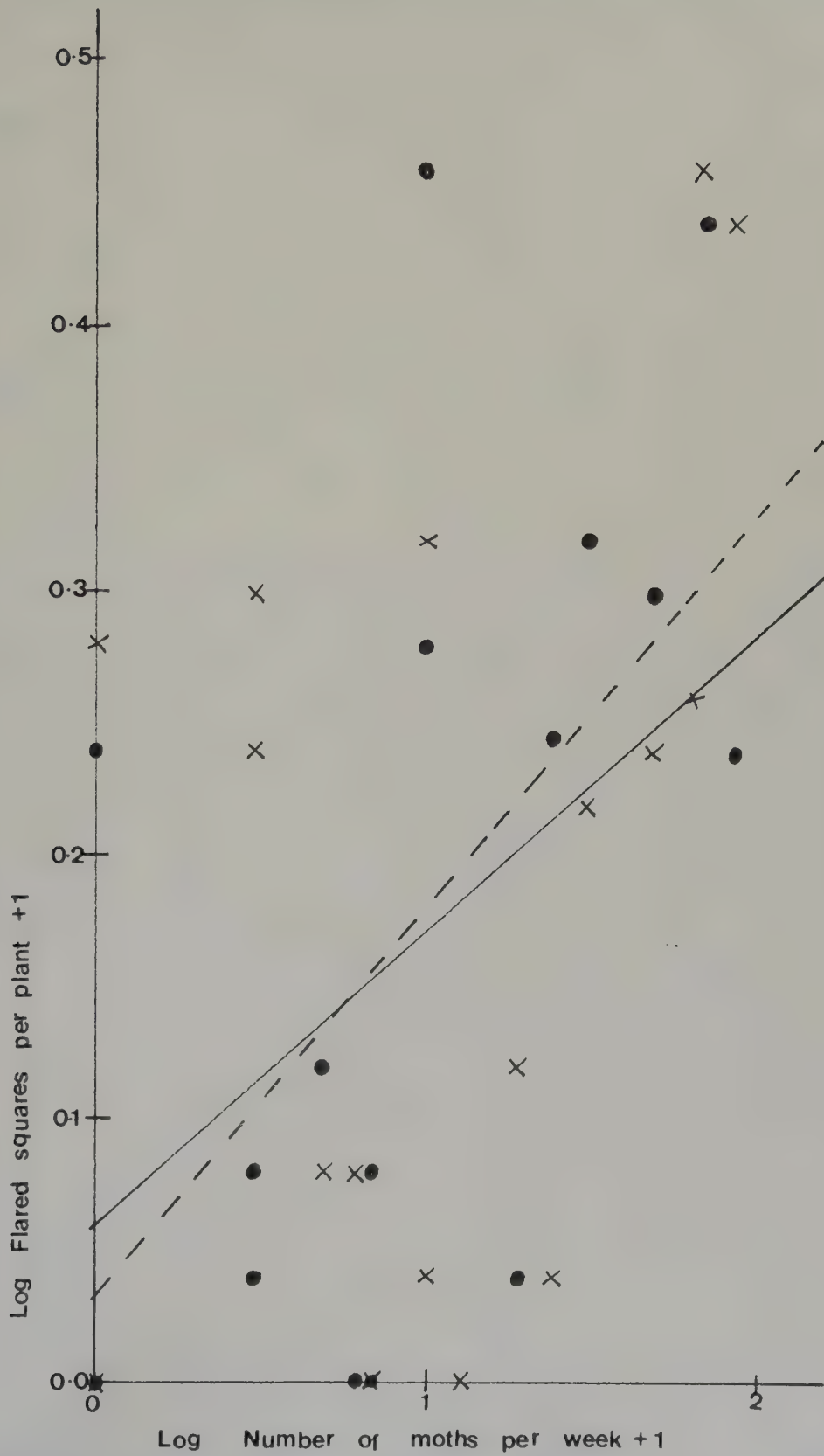


Figure 51— ii continued

b- Number of moths caught per week in relation to the level of damage

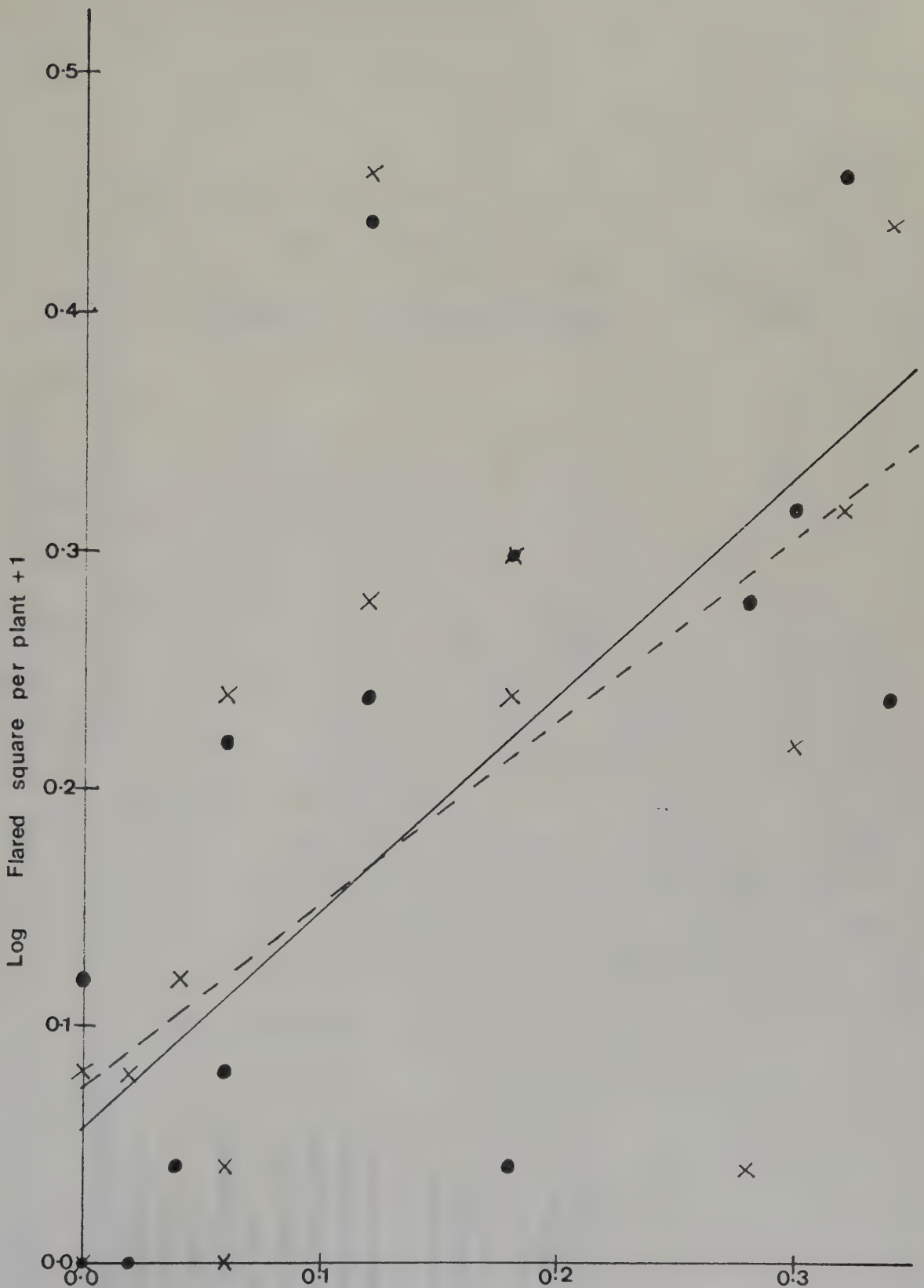


--- ● Number of moths vs number of flared squares per plant within the same week.
 $y = 0.031 + 0.148x$ $r = +0.590^*$, $p = 0.05$ $df = 15$

— X Number of moths vs number of flared squares per plant a week later
 $y = 0.058 + 0.113x$ $r = +0.416$ n.s. at $p = 0.05$, $df = 15$

Figure 51 continued

iii- The relationship between the level of infestation and damage to cotton:
Larval population per plant in relation to the level of damage



- ● Number of larvae per plant vs number of flared squares per plant in the same week.
 $y = 0.055 + 0.925x$ $r = +0.724^{****}$, $p < 0.001$, $df = 15$
- - - X Number of larvae per plant vs number of flared squares per plant a week later
 $y = 0.070 + 0.792x$ $r = +0.614^{**}$, $p = 0.01$, $df = 15$

Fig 52

- i- The pattern of *H. armigera* level of infestation and damage on cotton and adult male moth catches in a pheromone trap at Mwanhala 1983-84 season.

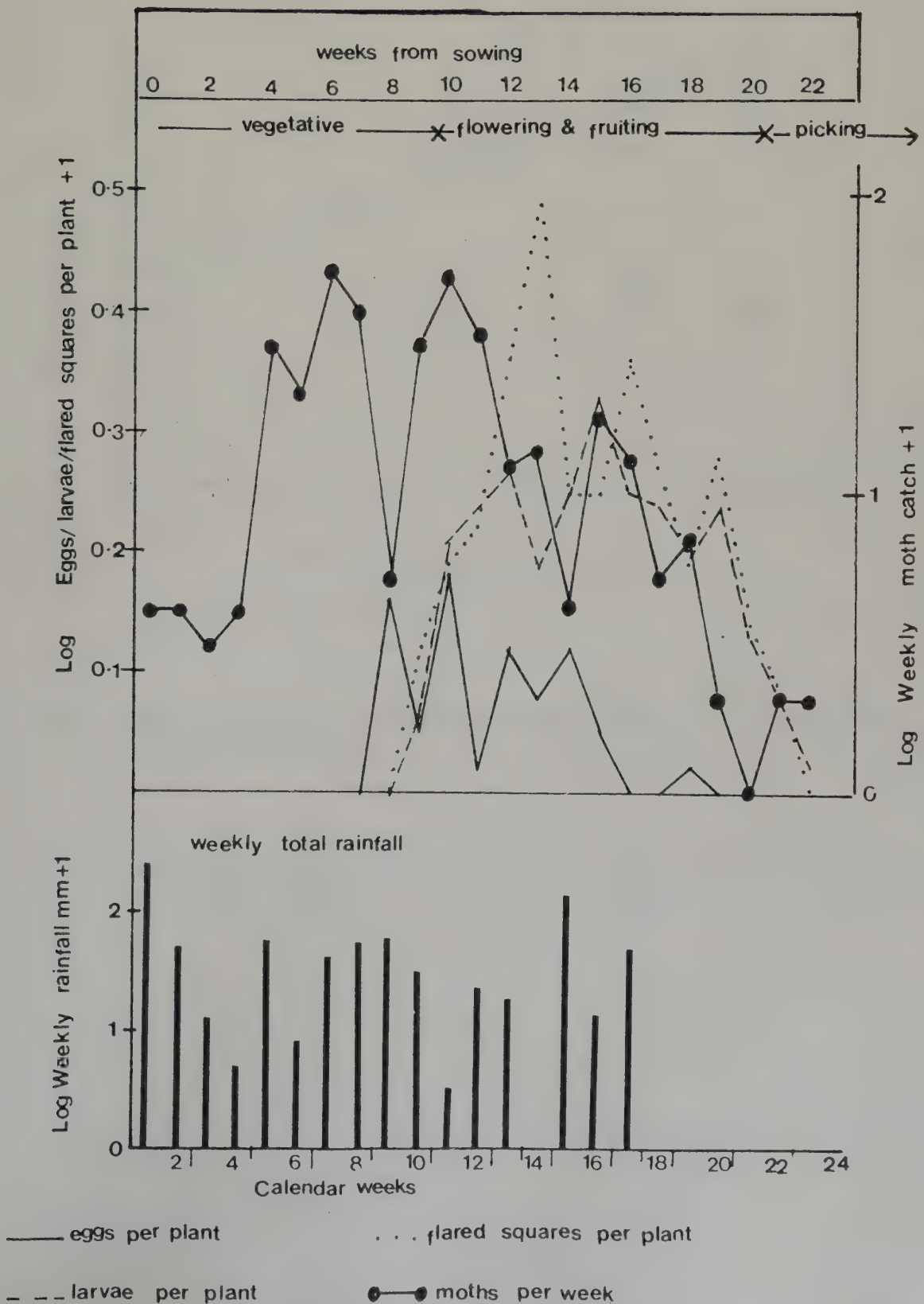
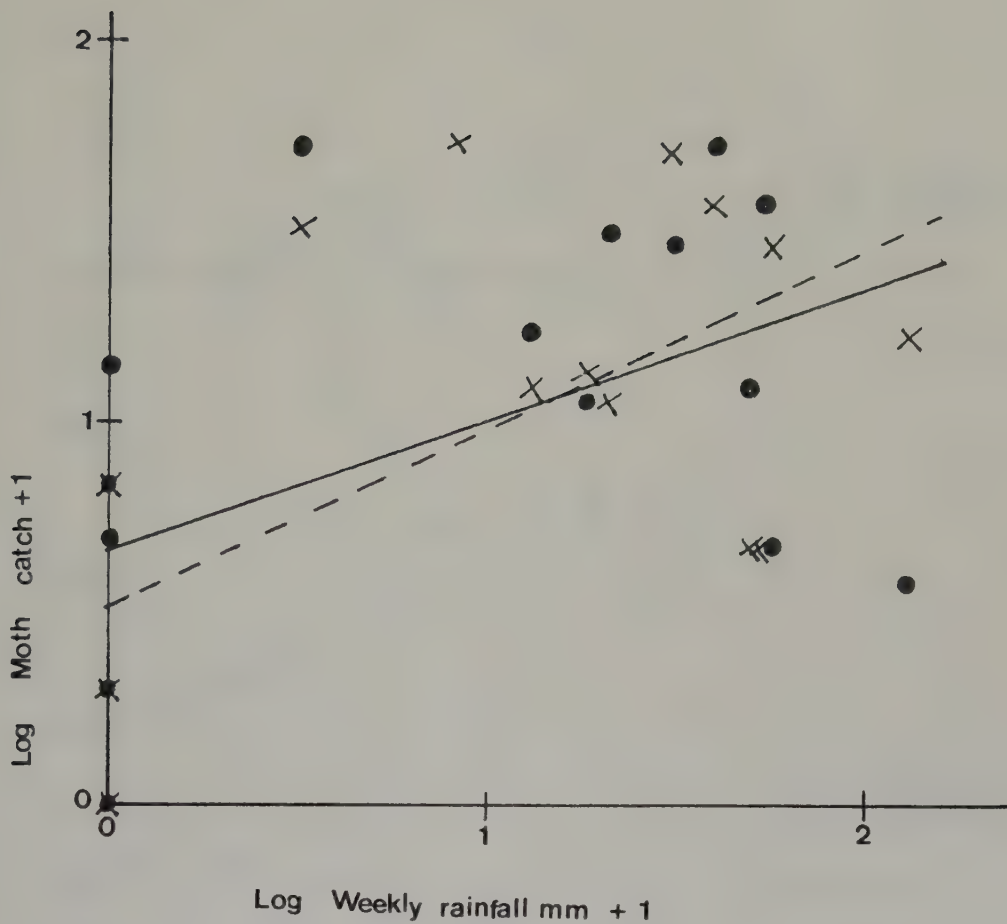


Fig 52 continued

- ii- The relationship between the weekly amount of rainfall and the number of moths caught per week in the pheromone trap



- ● amount of rainfall vs number of moths caught in the same week
 $y = 0.663 + 0.354x$ $r = +0.517^*$ $p = 0.05$ $df = 15$
- X amount of rainfall vs number of moths caught a week later
 $y = 0.515 + 0.476x$ $r = +0.685^{***}$, $p = 0.005$, $df = 15$

Fig 52 continued

- iii- The relationship between *H. armigera* level of infestation and damage to cotton and the number of male moths caught in the pheromone trap: moths caught per week in relation to the level of infestation and damage a week later.

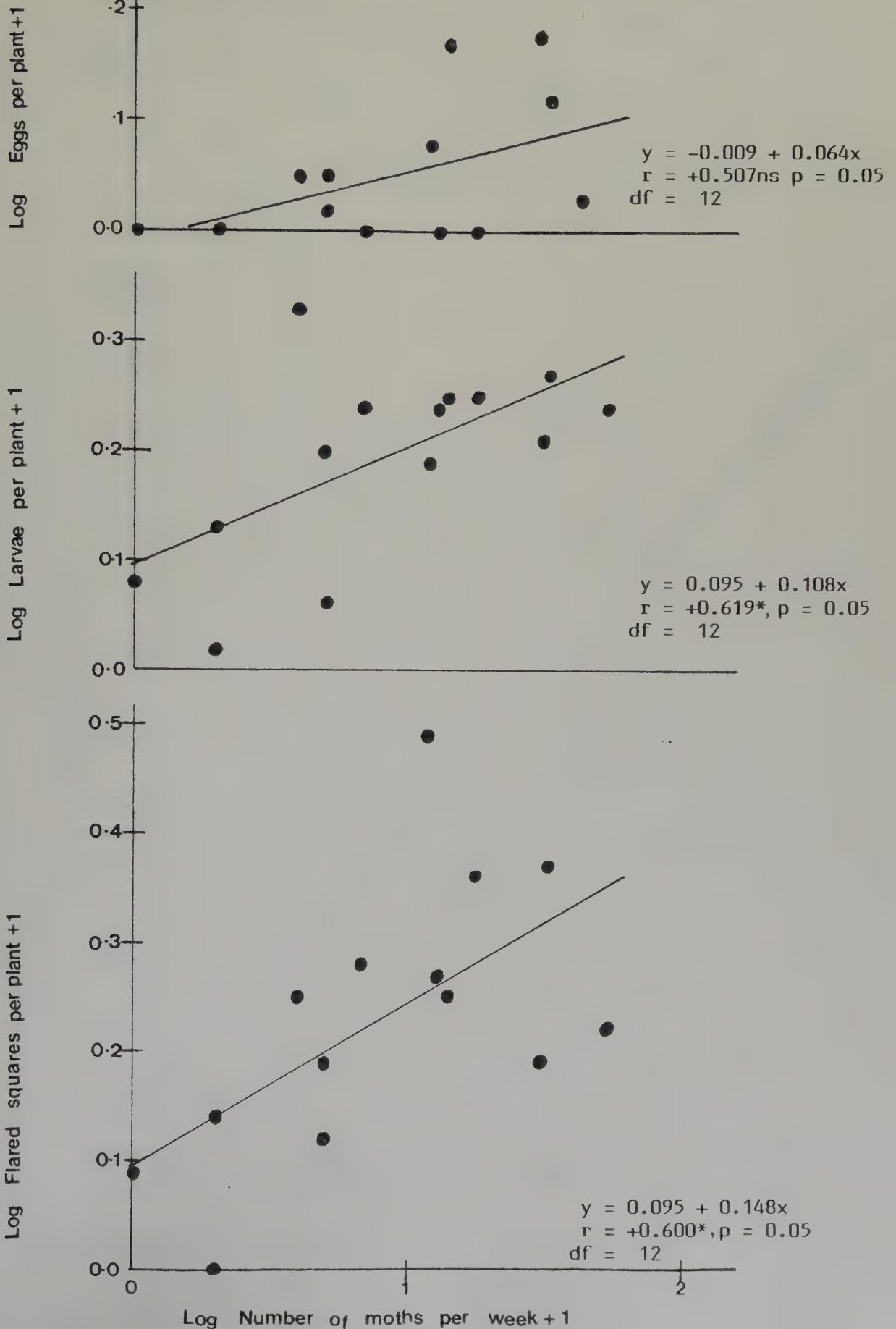
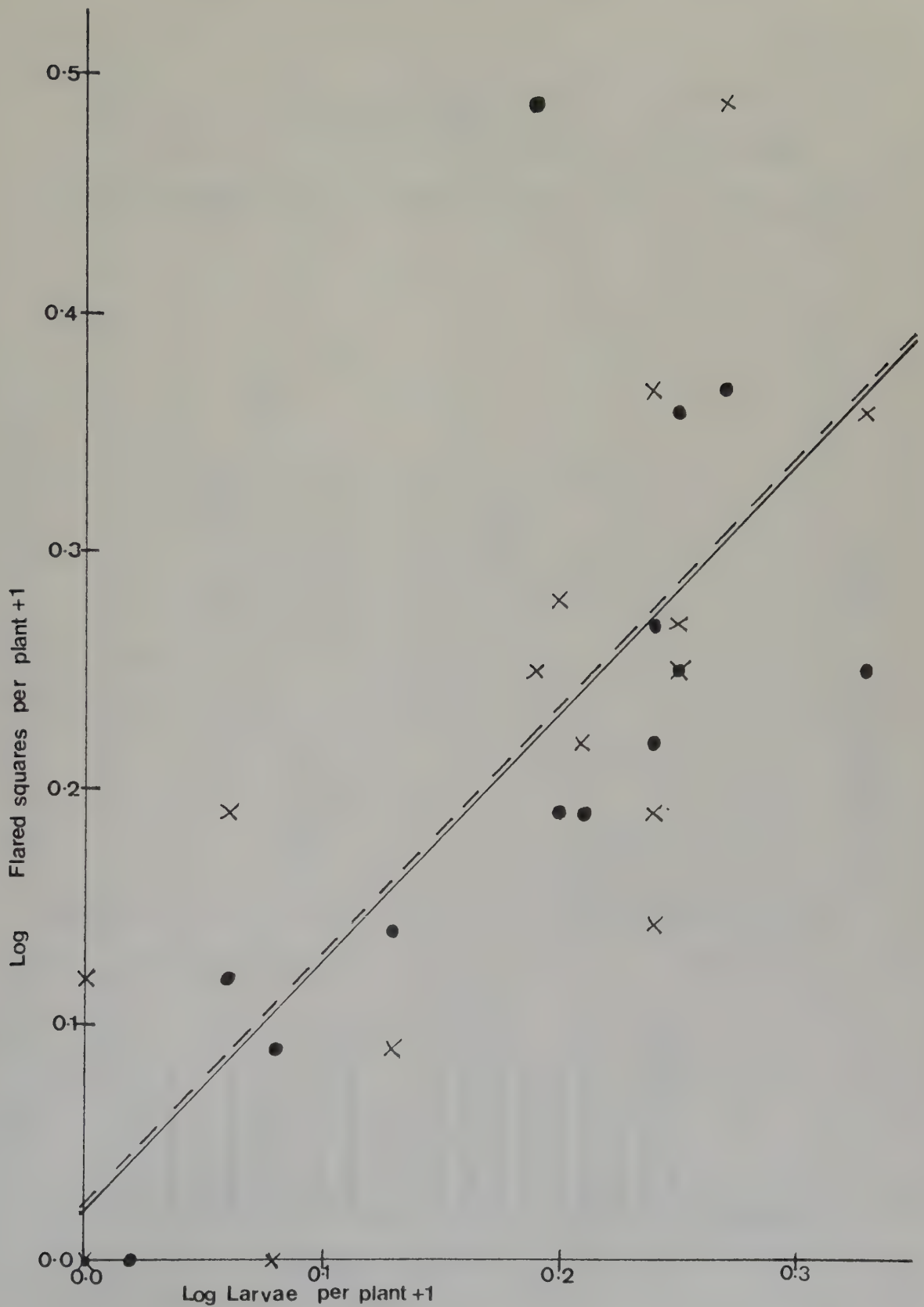


Figure 52 continued

- iv- The relationship between the level of larval population and the level of damage.



- Number of larvae per plant vs number of flared squares per plant within the same week
 $y = 0.018 + 1.08x$ $r = +0.821^{***}$, $p = 0.001$, $df = 15$
- X Number of larvae per plant vs number of flared squares per plant a week later
 $y = 0.022 + 1.06x$ $r = +0.818^{***}$, $p = 0.005$, $df = 15$

Fig 53 The pattern of *H. armigera* level of infestation and damage on cotton and adult male moth catches in a pheromone trap at Ukiriguru 1984-85 season.

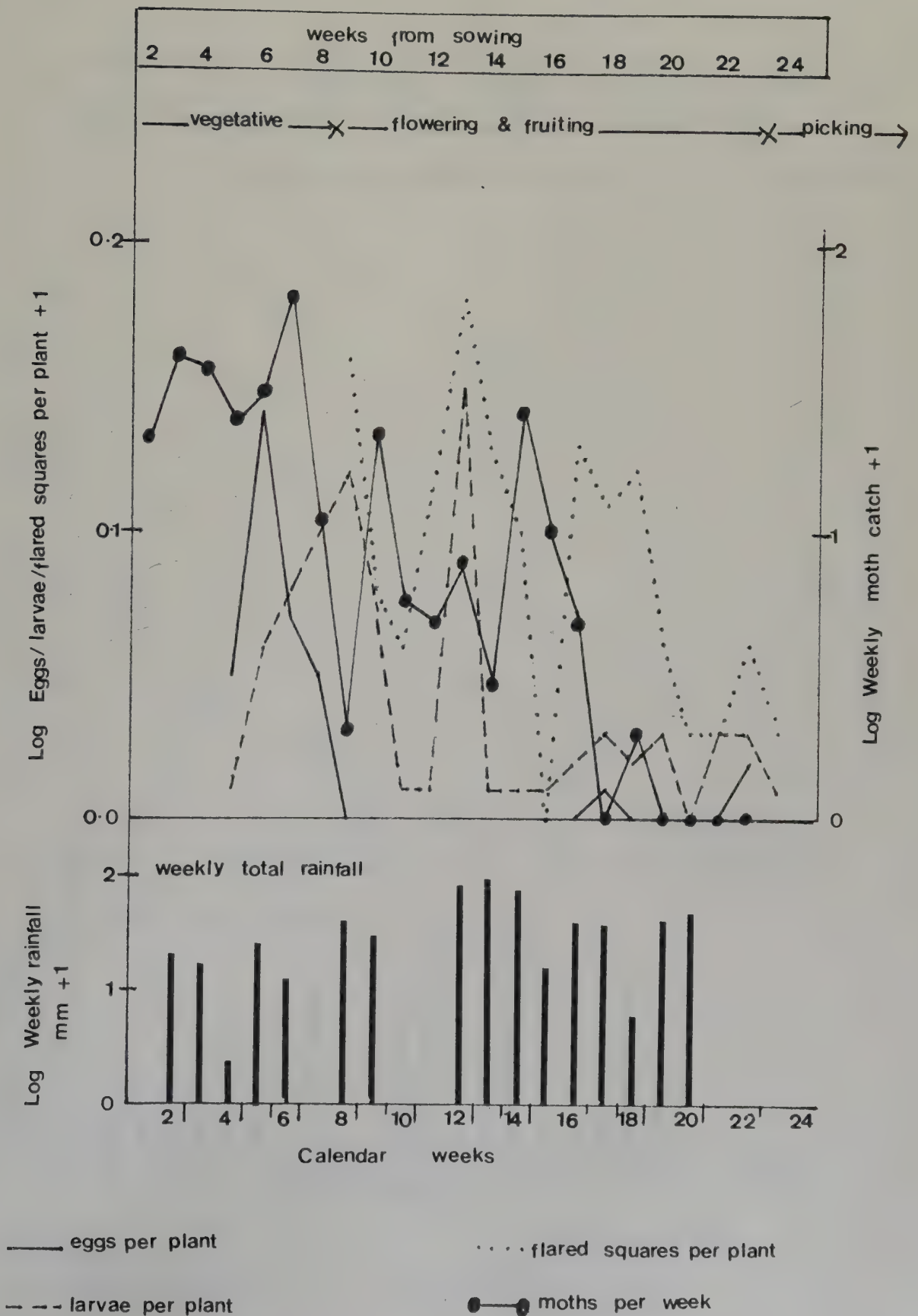


Fig 54

- i. The pattern of *H. armigera* level of infestation and damage on cotton and adult male moth catches in a pheromone trap at Mabuki 1984-85 season

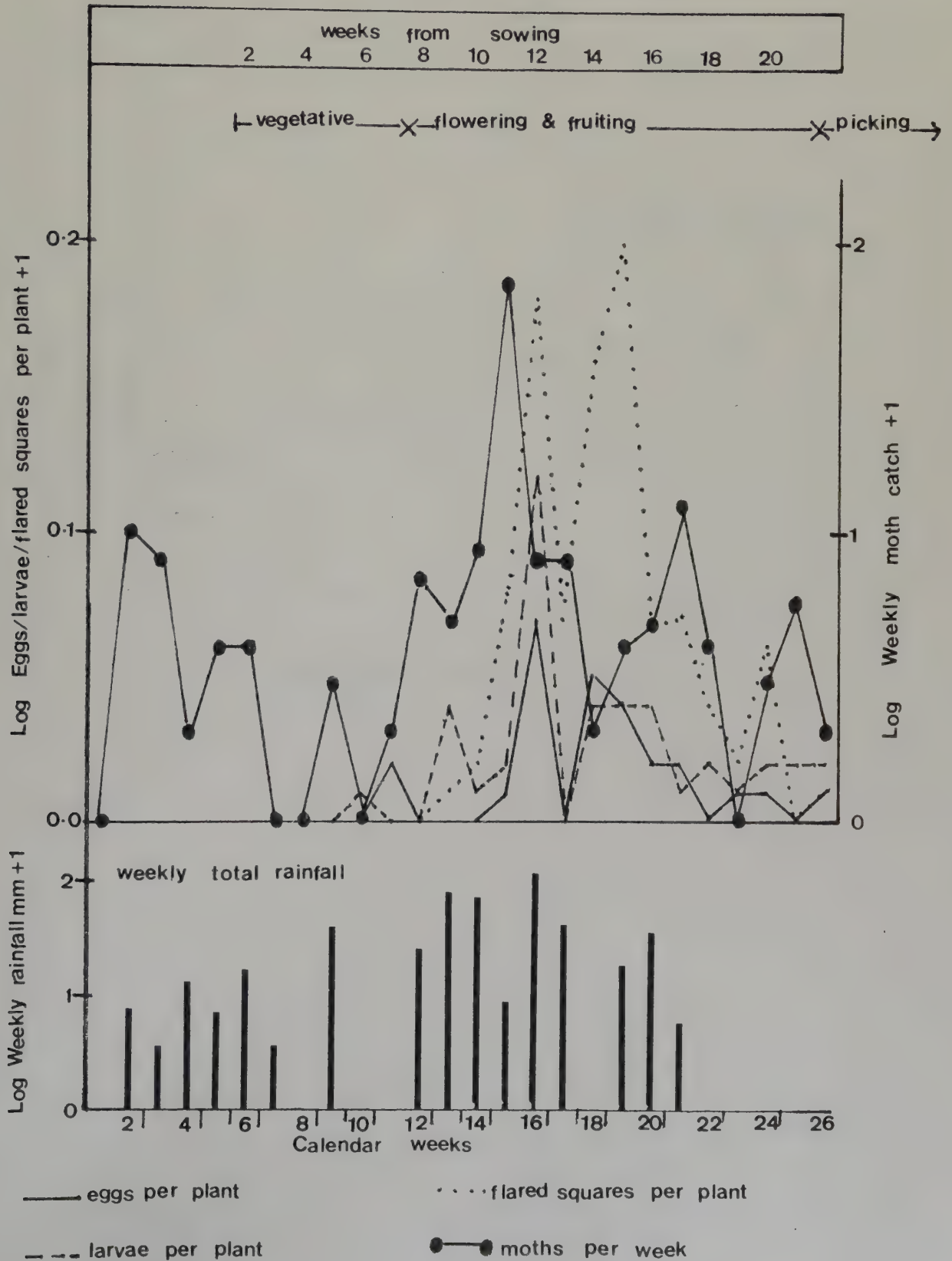


Figure 54 continued

ii- The relationship between the weekly amount of rainfall and the the number of moths caught in the pheromone trap.

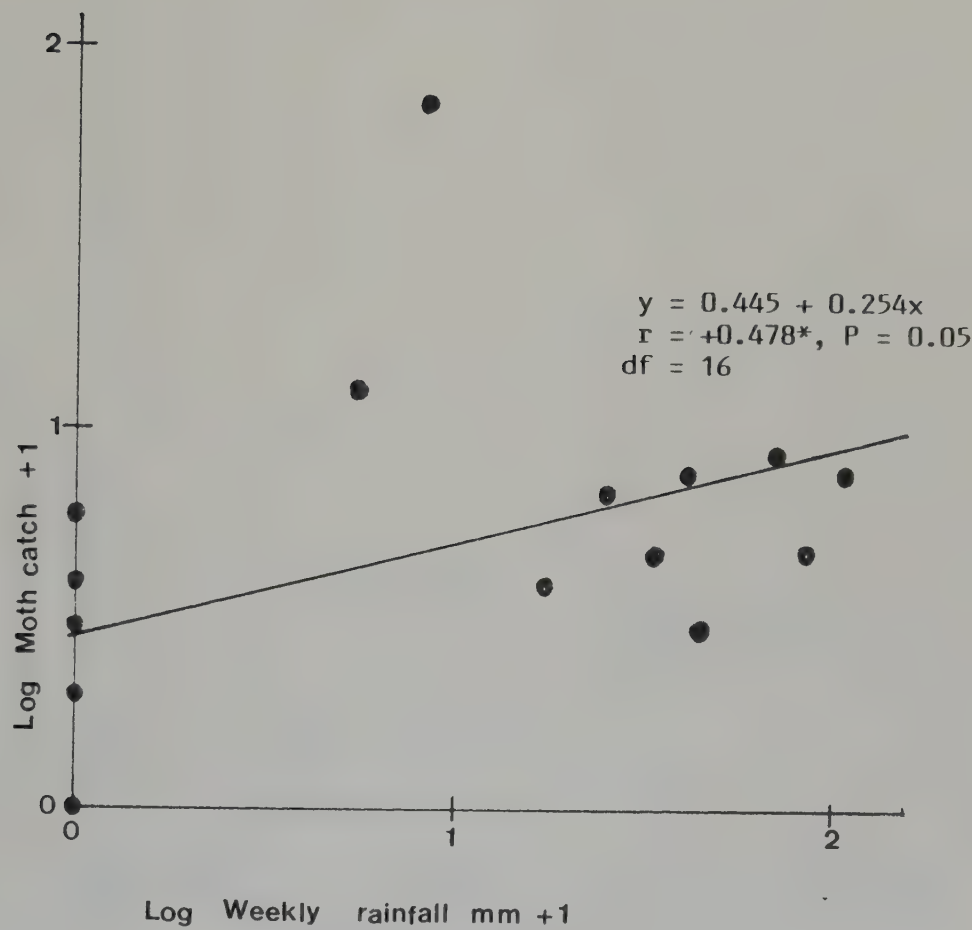


Figure 54 continued

- iii- The relationship between *H. armigera* level of infestation and damage to cotton and the number of male moths caught in the pheromone trap: weekly moth catch in relation to the larval population a week later.

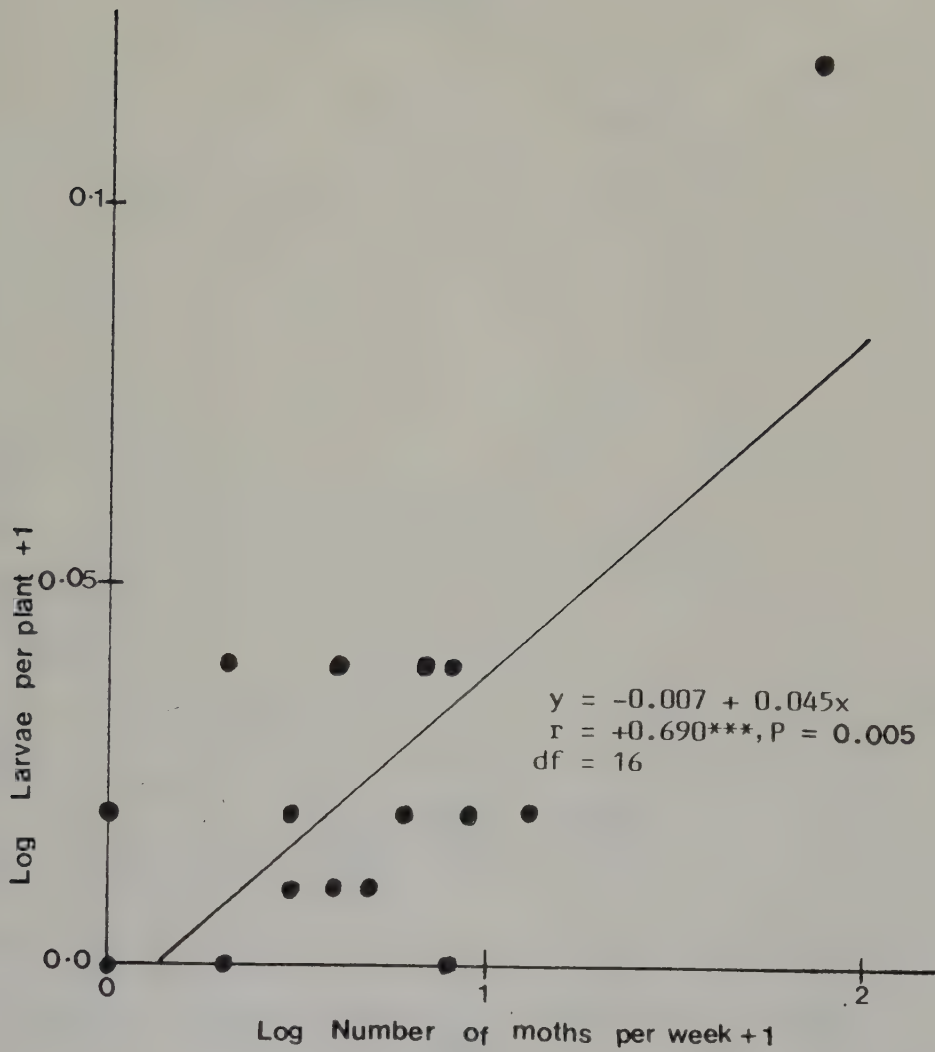


Figure 54 continued

iv- The relationship between H. armigera level of infestation and damage to cotton.

a- Level of eggs per plant in relation to the larval population within the same plant.

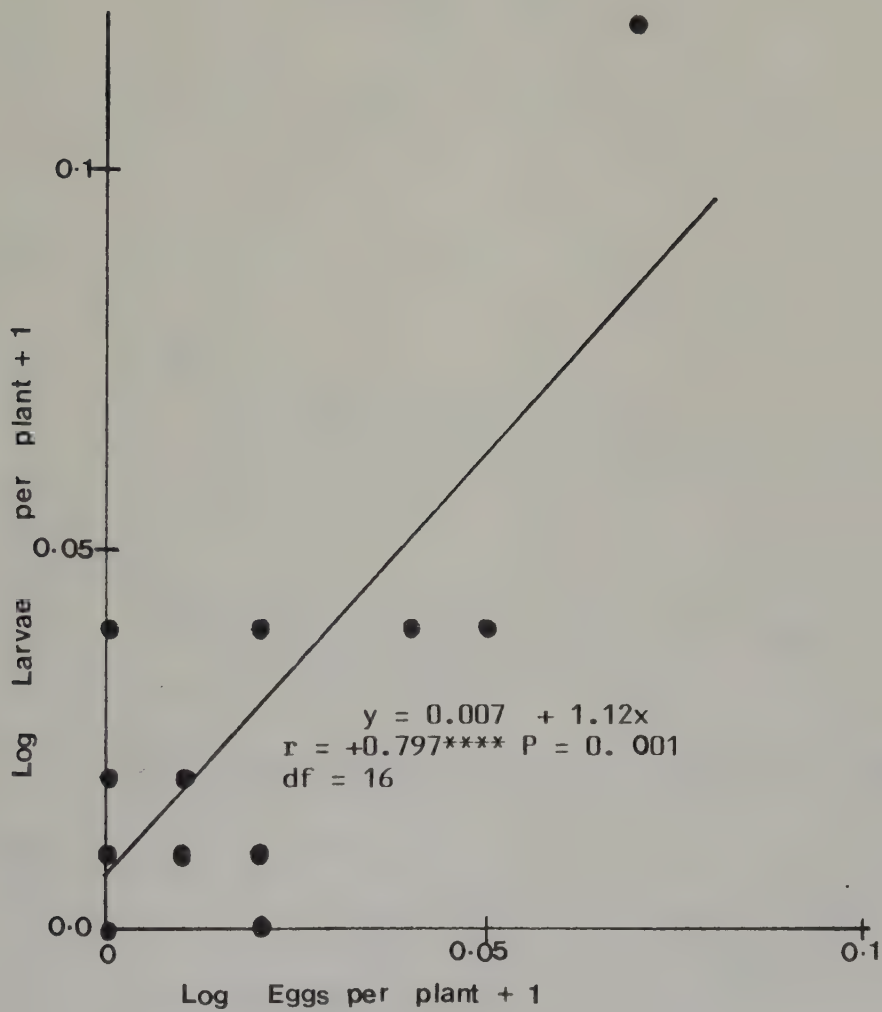
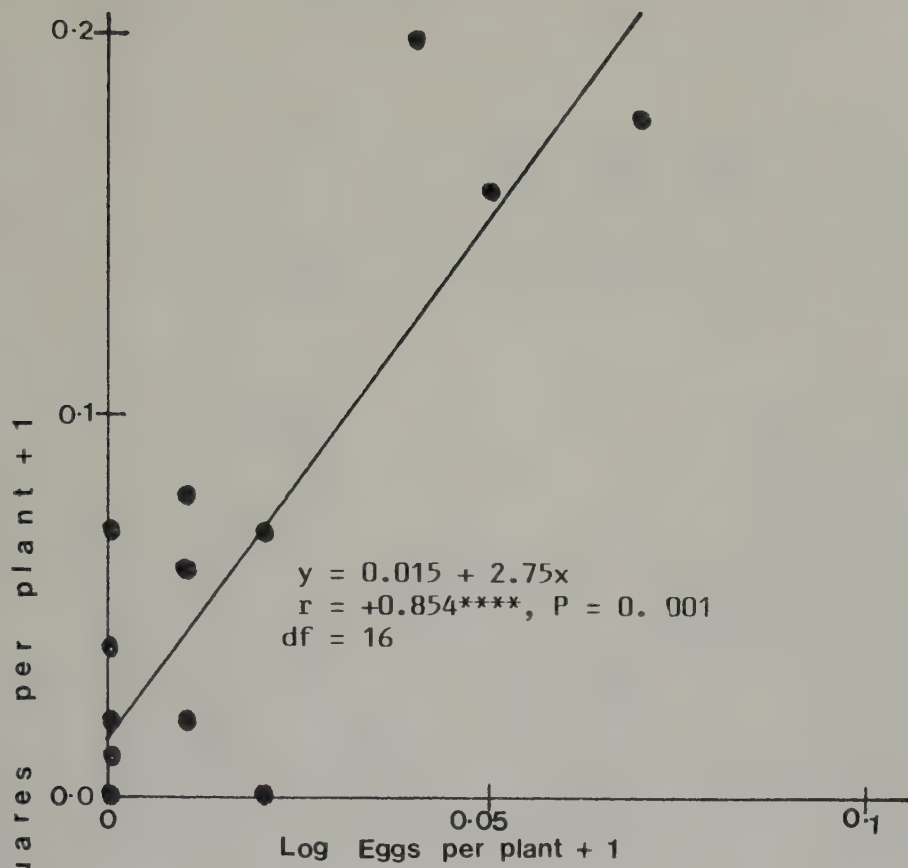


Figure 54-iv continued

b- Level of eggs per plant in relation to the level of damage



c- Larval population in relation to the level of damage

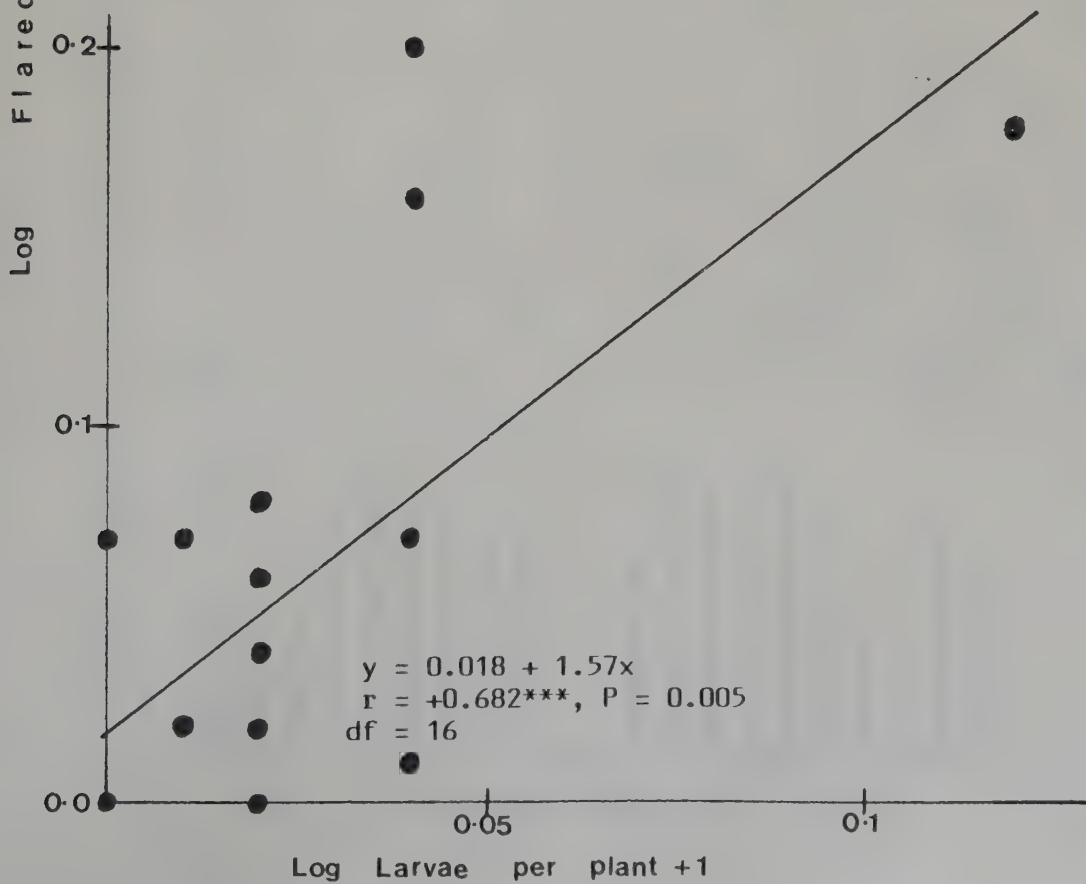


Fig 55 The pattern of *H. armigera* level of infestation and damage on cotton and adult male moth catches in a pheromone trap at Lubaga 1984-85 season.

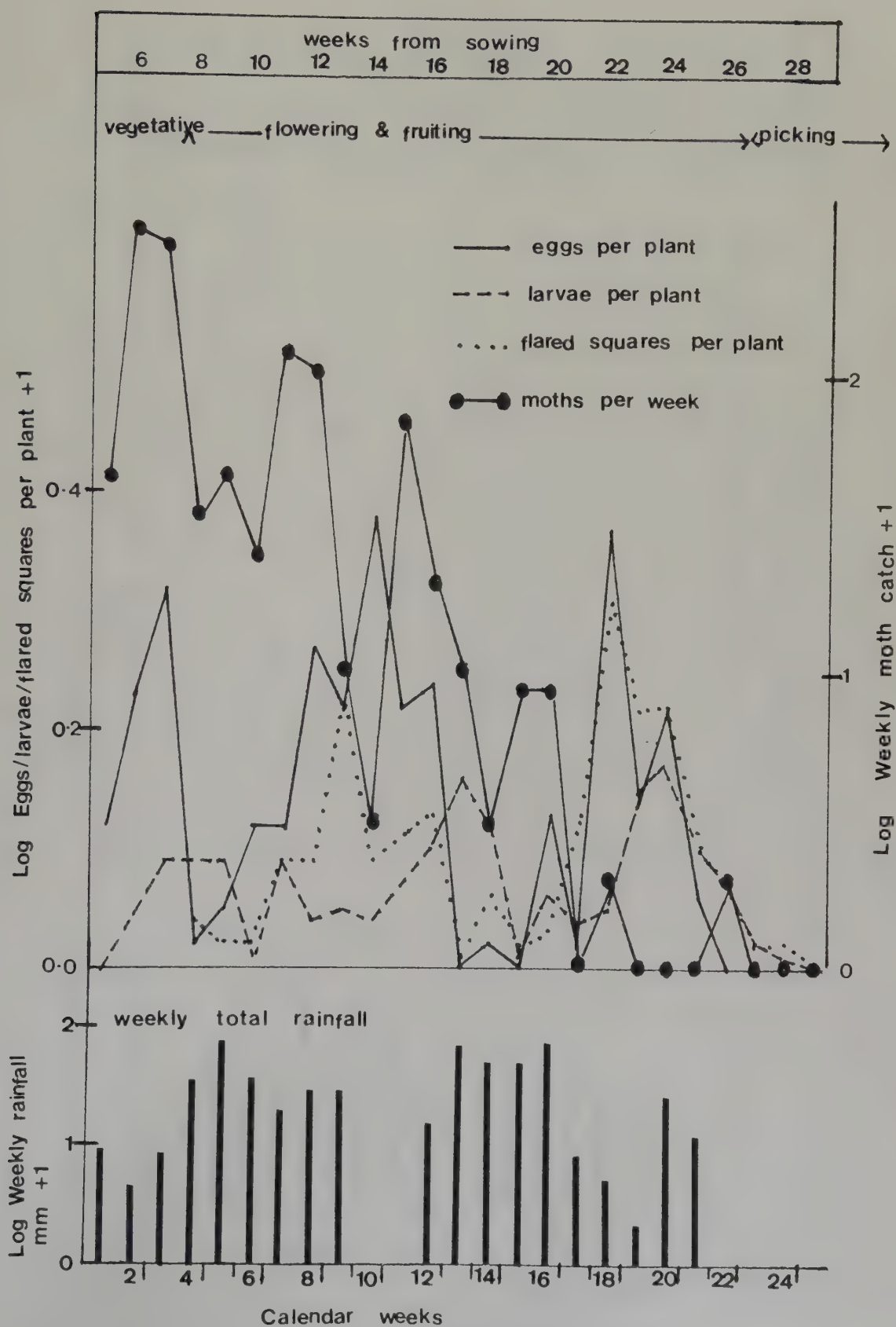
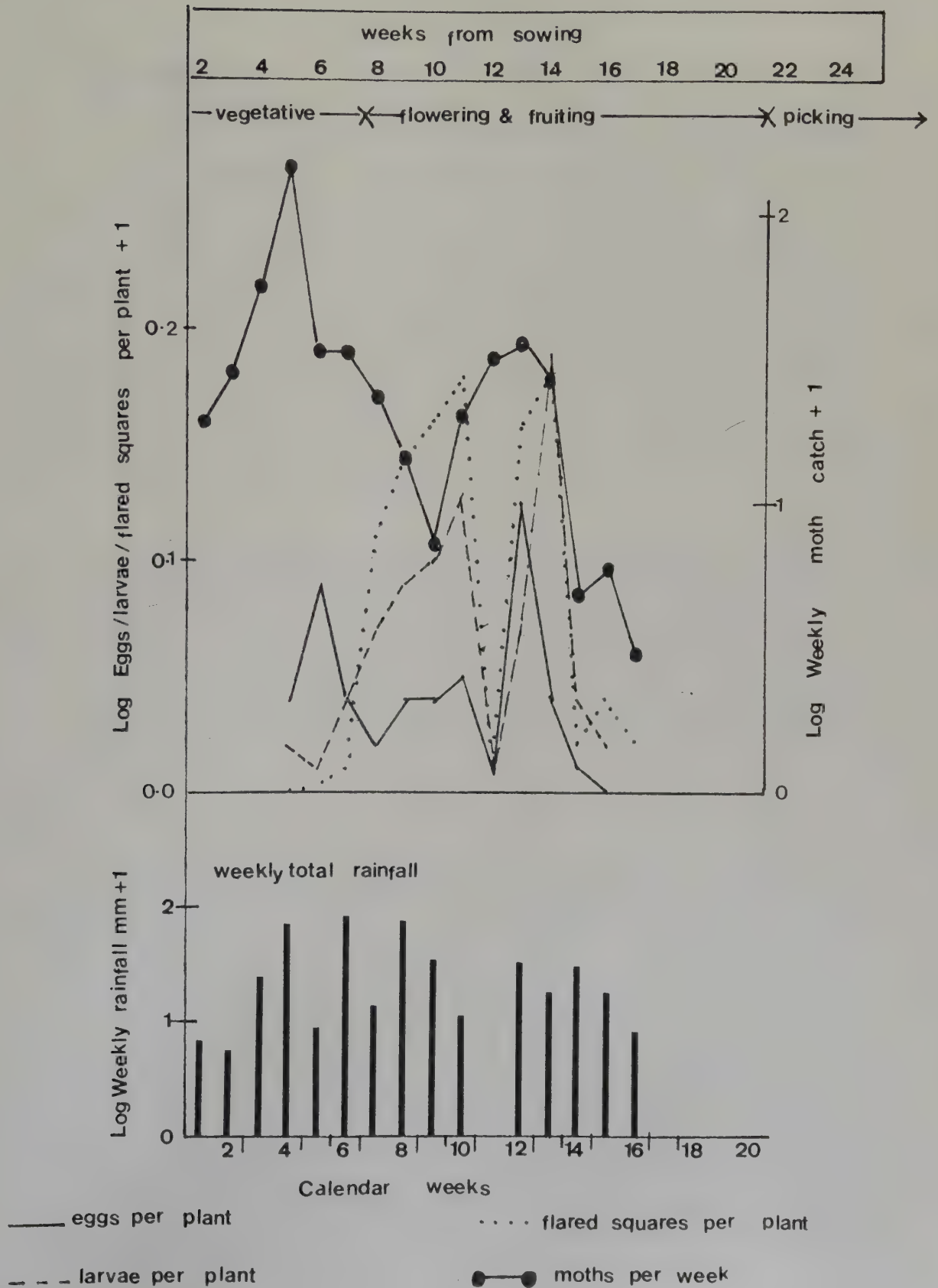


Figure 56 The pattern of *H. armigera* level of infestation and damage on cotton and adult male moth catches in a pheromone trap at Mwanhala 1984-85 season.



7. THE USE OF SCOUTING IN THE CONTROL OF H. ARMIGERA IN COTTON

IN WCGA

7.1 Background

Spraying of cotton in WCGA for control of H. armigera is based on a routine schedule. It does not take into account differences in pest population levels in time and space, so unnecessary treatments may be applied or there may also be failure to treat the crop when the pest level justifies treatment (see Section 1.3.2). In view of such problems, scouting trials were started in the 1970's to find a suitable H. armigera density threshold on which to base insecticide application only when necessary.

It might be more efficient to adopt threshold spraying where

- a) scouting improves timing of spray application or fine tuning
- b) scouting identifies years of high attack thus requiring more sprays or alternatively, years of low attack when insecticide can be saved.

Thus, a strategy of scouting for eggs and larvae and spraying to control H. armigera in cotton in Tanzania began in the 1972-73 season (Percy and Kirkby, 1975; unpublished report). By the end of the 1974-75 season, the results were still inconclusive because there was no clear relationship between threshold levels of H. armigera and the final yield of seed cotton. This is possibly because the cotton varieties can compensate for loss of fruiting points (Percy and Kirkby, 1975). This work showed that it is not possible to use egg

counts alone for determining the need to spray, e.g. low level of oviposition over long periods could do much damage than limited heavy oviposition. However, Percy and Kirkby (1975) concluded that the routine spraying regime could be usefully modified by increasing the spray interval when egg counts were very low over an extended period.

A few farmers in WCGA now spray their cotton based upon a 'scouting' system determined by the abundance of flared squares and/or fully grown larvae in the crop (Nyambo, 1981). A major disadvantage of this system is that by the time the farmer notices the bollworm larvae, damage has already been done to the crop. Furthermore, a larger dosage of insecticide is required to kill the well-grown larvae. So scouting trials were redesigned to identify a suitable threshold that could be used as a guideline to the farmers who already 'scout' their cotton fields for damage. A damaged cotton bud flares once the larva moves out and such a bud remains on the plant for up to a week before it is shed. Thus, monitoring for flared squares as frequently as once a week may provide sufficient time to control further crop loss by killing the larvae while they are still small.

7.1.1 Methodology

The trials started in the 1980-81 season and continued to the 1984-85 season. The trials in randomized block designs were sited at Ukiriguru and its substations where reliable supervision and record keeping were guaranteed. Each trial area varied between 1.2 to 2ha depending on site. All the agronomic practices were as recommended

for cotton growing in WCGA.

All treatments were scouted for H. armigera eggs and larvae twice a week but only the first of the two counts was used for decision making (Table 32). The second egg and larvae count took place three days after the first. Flared squares were counted once a week and on the same day as the first eggs and larval count of the week. If a treatment level was reached, spraying was done on the day after the count (Table 32). Spraying using the threshold data did not start until 8 weeks after sowing because early infestation and damage do not normally cause economic crop loss (Brown, 1962).

Endosulfan 25% ULV was sprayed at Ukiriguru and Mabuki sites and DDT35/Methidathion 15% ULV was used at Lubaga, Mwanhala and Kisuke. A hand held Micron ULVA pump which is used by cotton farmers in WCGA was used to apply the insecticide at recommended rates of 2.5l per ha and a swath width of 4.5m (5 ridges of 90cm or 3 ridges of 1.5m width depending on site). Both chemicals achieve similar pest control levels irrespective of site. However, the price of endosulfan was used throughout in the comparison of the economic returns for all the sites.

In the economic analysis of results, only the cost of insecticide was used and all the other costs were considered equal. However, the extra cost of scouting and harvesting, grading and transporting the extra seed cotton yield to the buying post are important. In this exercise, the opportunity cost of the farmer's

Table 32. Scouting instructions for the Scouting Trial

NOTES ON TREATMENTS

1. Start pest counts 8 weeks after planting
2. Do pest counts twice each week. The second count should be 3 days after the first eg counts on Monday and Thursday, or Tuesday and Friday.
3. The first pest count of each week only is to be used for the spray decision. Spray if necessary on the day after the count e.g. count on Monday spray if necessary on Tuesday.
4. White flower and flared square counts to be done the same day as the first pest count of the week. The flared square counts are then to be used for the spray decision. eg. pest count on Monday, flared square count on Monday-spray if necessary on Tuesday.
5. Treatments A, B, C and D can be sprayed starting 8 weeks after planting if necessary. Treatment E to start 10 weeks after planting.
6. Record on the sheets following this the eggs/plant, larvae/plant and flares/plant from the first count of the week only. Use this for the spray decision. If the treatment is sprayed, give the date (Appendix 13a).
7. In the remarks column of the pest count sheet record the numbers of small and large American bollworm larvae. (Appendix 13b).
8. Count the numbers of undamaged buds at the same time and on the same plants as the white flower and flared square counts.
9. Use the spraying threshold guide provided (Appendix 14).

Note carefully: Count only buds and NOT Bolls.

BUDS = VITUMBA

labour in relation to the extra time spent scouting and harvesting the extra crop is estimated to be very low. From research experience, the opportunity cost of scouting for damaged buds is as follows (an average of 1 min per plant is assumed, 50 plants to be examined):

Time required per week $\approx 50 \text{ min} \equiv 0.12 \text{ man hours per day}$

Critical period for scouting, 8th to 20th week after sowing, this giving 12 weeks of scouting $\equiv 12 \times 0.12 \text{ man hours}$

The current minimum labour cost $\approx 31.00 \text{ Tz.sh. per day (7 hours)}$

\therefore Cost of scouting per season $= 12 \times 0.12 \times 31.00 \text{ Tz.sh.}$
 $= 44.30 \text{ Tz.sh.}$

The treatment thresholds are shown in Table 33 and the insecticide prices and farmers price of seed cotton in Tables 34 and 35 respectively.

From the 1980-81 season results, treatment C threshold was considered too low to initiate economic spray applications (see also 1980-81 discussion of results). Treatment D gave the poorest economic return compared to the other sprayed treatments at all sites. Thus, these two treatments were considered unsuitable for further investigation.

Treatments B and D were introduced in 1981-82 (Table 33(2)). Treatment B, a lower damage threshold than A was used as a check on A which had given promising results in the previous season. Treatment

Table 33. Treatments threshold assessed in the scouting trials at Ukiriguru and its substations, 1980-81 to 1984-85 seasons.

(1) 1980-81 season: Ukiriguru, Lubaga and Mwanhala sites

Code	Treatment
A	Spray when there are 0.5 or more <u>H. armigera</u> damaged buds or flowers per plant
B	Spray when there are 0.3 eggs or more or 0.15 small larvae or more per plant
C	Spray when there are 0.2 eggs or more or 0.10 small larvae per plant
D	Spray when there are 0.15 or more small larvae per plant
E	Spray six times at two week intervals starting 10 weeks after sowing (routine (calendar) spraying
F	Unsprayed

(2) 1981-82 season: Ukiriguru, Lubaga and Kisuke sites

A	Spray when there are 0.5 or more <u>H. armigera</u> damaged buds or flowers per plant
B	Spray when there are 0.4 or more <u>H. armigera</u> damaged buds or flowers per plant
C	Spray if there are 0.3 eggs or more or 0.15 small larvae or more per plant
D	Spray if there are 0.4 eggs plus small larvae per plant
E	Spray six times at two week intervals starting 10 weeks after sowing
F	Unsprayed

(3) 1982-83 season: Ukiriguru and Lubaga sites

A	Spray when there are 0.5 or more <u>H. armigera</u> damaged buds or flowers per plant
B	Spray when there are 0.4 or more <u>H. armigera</u> damaged buds or flowers per plant
C	Spray when there are 0.3 eggs or more or 0.10 or more small larvae per plant
D	Spray when there are 0.4 eggs plus small larvae per plant

Table 33 (Continued)

(3) 1982-83 season (continued)

Code	Treatment
E	Spray six times at two week intervals starting 10 weeks after sowing
F	Unsprayed

(4) 1983-84 season: Ukiriguru, Lubaga, Mabuki and Mwanhala sites

A	Spray when there are 0.5 or more <u>H. armigera</u> damaged buds or flowers per plant
B	Spray when there are 0.4 or more <u>H. armigera</u> damaged buds or flowers per plant
C	Spray six times at two week intervals beginning 10 weeks after sowing
D	Unsprayed

(5) 1984-85 season: Ukiriguru, Mabuki and Lubaga sites

A	Spray when there are 0.5 or more <u>H. armigera</u> damaged buds or flowers per plant per count
B	Spray when there are 0.5 or more <u>H. armigera</u> damaged buds or flowers per plant per count or in two consecutive counts
C	Spray when there are 0.4 or more <u>H. armigera</u> damaged buds or flowers per plant per count.
D	Spray when there are 0.4 or more <u>H. armigera</u> damaged buds or flowers per plant per count or in two consecutive counts
E	Spray six times at two week intervals beginning 10 weeks after sowing.

Table 34. Cost of insecticides Tz. sh. per l.: 1980-81 to 1984-85.

Season	Name of insecticide	
	Endosulfan 25% ULV	DDT35/Methidathion 15% ULV
1980-81	26.00	31.00
1981-82	28.25	32.40
1982-83	32.90	35.96
1983-84	36.25	38.68
1984-85*	71.90	

* endosulfan 25% ULV was used on all the sites.

Table 35. Farmers price of seed cotton Tz. sh. per kg for the period 1980-81 to 1984-85 season.

Season	Grade A Cotton	Grade B Cotton
	(AR)	(BR)
1980-81	3.70	1.70
1981-82	4.70	2.50
1982-83	6.00	3.20
1983-84	8.40	4.20
1984-85	13.50	8.50

D was introduced to assess the value of using either eggs or larvae for decision making.

At the end of the 1981-82 season it became evident that the larval threshold in treatment C (0.15 larvae) Table 33(2), was too high to give good economic returns from spraying. Thus in 1982-83 season a level of 0.10 larvae was introduced (Table 33(3)).

After 1982-83 season the egg and larvae treatment thresholds were not assessed any further because for practical purposes, farmers would not be willing to scout for eggs and small larvae.

7.1.2 Results and discussion

7.1.2.1 1980-81 season - At all the sites, none of the spraying thresholds triggered a spray before the 10th week after sowing (Fig. 57). At Ukiriguru (Fig. 57a), sprays based on thresholds were applied between weeks 11 and 14 after sowing; at Lubaga (Fig. 57b) between week 15 and 20 and at Mwanhala (Fig. 57c) between weeks 10 and 18 after sowing. Thus, any sprays applied before or after the initial periods may not have caused a significant yield increase because the level of infestation and damage was low (Fig. 57). Overall, there was more response to spraying at Ukiriguru and Mwanhala than at Lubaga, and thresholds A, B and C gave equal or better monetary returns compared to the routine treatment (Table 36).

Treatment A, based on flared square counts triggered three sprays at Mwanhala and at Ukiriguru despite the low level of

Fig 57

The pattern and level of *H. armigera* infestation and damage on unsprayed cotton plots at Ukiriguru, Lubaga and Mwanhala in 1980-81 showing spray timing on the sprayed plots

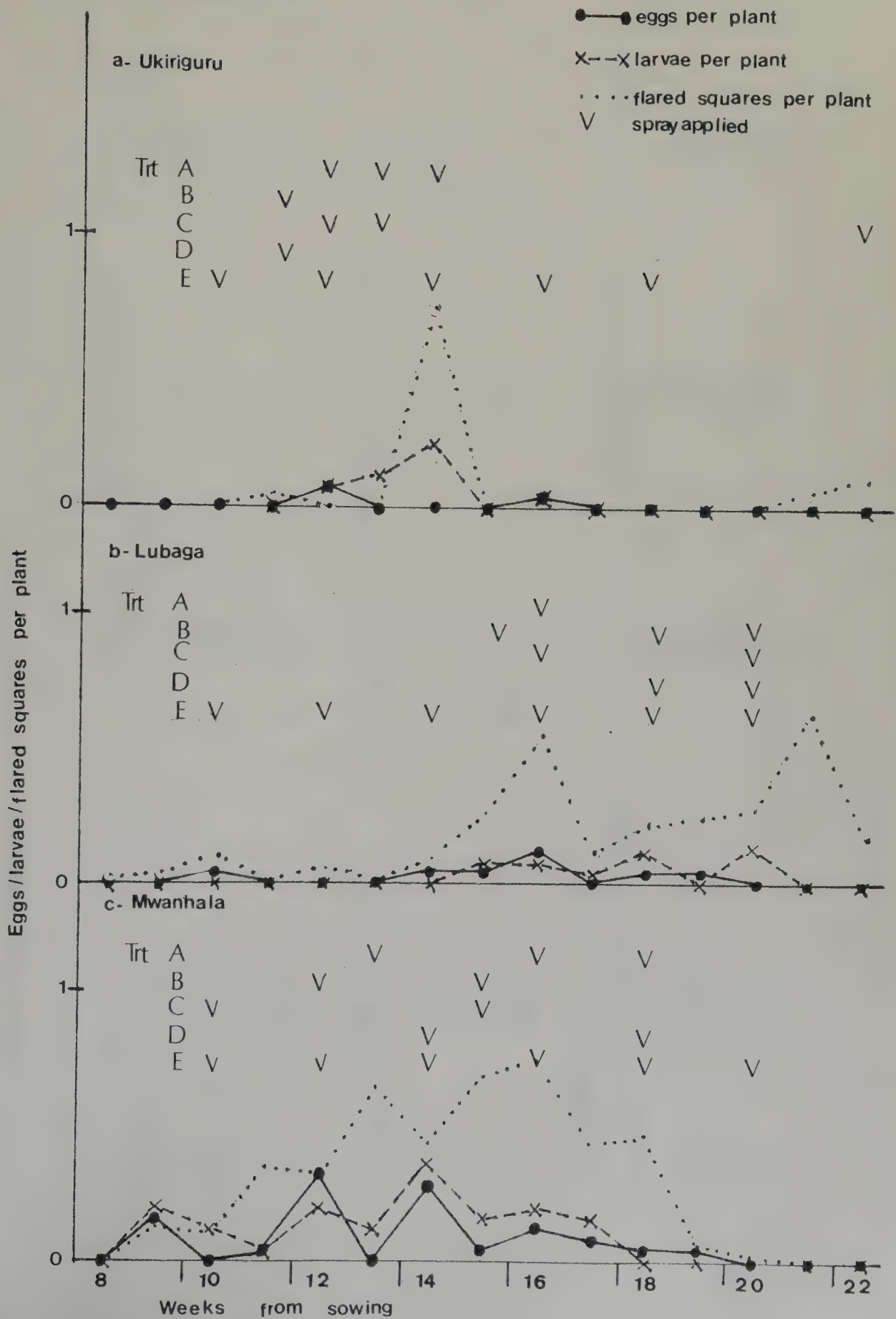


Table 36. Cost/benefit analysis of the seed cotton yields in relation to timing and numbers of spray applications in the 1980-81 season.

(1) Ukiriguru site:

Treatment	Mean yield kg/ha(%AR)	Number of sprays	Gross value of crop Tz.sh./ha	Cost of insecticide Tz.sh./ha	Total revenue Tz.sh. per ha
A	659(93)	3	2346	195	2151
B	609(94)	1	2180	65	2115
C	654(93)	3	2328	195	2133
D	559(93)	1	1990	65	1925
E	722(94)	5	2585	325	2260
F	431(91)	0	1517	0	1517
SE	±41.7				

Treatment	Yield gain kg/ha over unsprayed	% yield gain over unsprayed	Monetary gain (+) or loss (-) over the routine regime Tz.sh./ha	%
A	228	52.9	-109	-4.8
B	178	41.3	-145	-6.4
C	223	51.7	-127	-5.6
D	128	29.7	-335	-14.8
E	291	67.5		

(2) Lubaga site:

Treatment	Mean yield kg/ha(%AR)	Number of sprays	Gross value of crop Tz.sh./ha	Cost of insecticide Tz.sh./ha	Total revenue Tz.sh. per ha
A	1146(85)	1	3818	65	3753
B	1114(89)	3	3644	195	3449
C	1194(85)	2	3905	130	3775
D	1072(87)	2	3533	130	3403
E	1295(89)	6	4042	390	3652
F	1078(85)	0	3665	0	3665
SE	±74.4				

Table 36 (Continued)

(2) Lubaga site: (continued)

Treatment	Yield gain kg/ha over unsprayed	% yield gain over unsprayed	Monetary gain (+) or loss (-) over the routine regime Tz.sh./ha	%
A	68	6.3	+101	+2.7
B	36	3.3	-203	-5.5
C	116	10.7	+123	+3.4
D	- 6	-0.5	-249	-6.8
E	217	20.13		

(3) Mwanhala site:

Treatment	Mean yield kg/ha(%AR)	Number of sprays	Gross value of crop Tz.sh./ha	Cost of insecticide Tz.sh./ha	Total revenue Tz.sh. per ha
A	1103(85)	3	3517	195	3322
B	1064(82)	2	3399	130	3269
C	920(85)	2	2895	130	2765
D	571(85)	2	1708	130	1578
E	1067(84)	6	3141	390	2751
F	740(84)	0	2501	0	2501
SE	±133.7				

Treatment	Yield gain kg/ha over unsprayed	% yield gain over unsprayed	Monetary gain (+) or loss (-) over the routine regime Tz.sh./ha	%
A	363	49.0	+571	+20.7
B	324	43.8	+518	+18.8
C	180	24.3	+ 14	+ 0.6
D	-169	-22.8	-1173	-42.6
E	327	44.2		

infestation, and although this threshold gave lower yield of seed cotton compared to the routine treatment, it was one of the best at both sites in terms of economic returns (Table 36(1) & (3)). At Lubaga, this threshold triggered only one spray and the net economic return was 3% higher than the routine treatment (Table 36(2)).

Spraying in treatment B (0.3 eggs or 0.15 larvae per plant) was triggered by the larval threshold at all sites except at Lubaga where one of the sprays was based on egg counts. Considering that the larval threshold of treatment B and D (0.15 larvae per plant) are similar, treatment B performed better than D. Treatment C produced similar yields as threshold A at Ukiriguru. At Lubaga the net economic return obtained by threshold C was fairly good when compared with the routine treatment. At Mwanhala, threshold C produced less seed cotton compared to the routine treatment but the yield differences were not statistically significant. Treatment C was therefore as good as treatment A, B and the routine treatment. However, in view of the low level of H. armigera attack during the season, the low threshold level of C would have been expected to provide more accurate timing of spray applications and so to have given higher yield and economic returns than the other treatments. In a situation where egg laying continues at a moderate level for an extended period rather than occurring in peaks, egg or larval counts could be continuously over the threshold level and thus lead to an excessive number of spray applications where low thresholds are used, which may not be economical. During the 1979-80 season, treatment C triggered seven sprays at weekly intervals at Geita Cotton Project

Area but the net economic returns obtained was substantially less than the calendar spraying regime. In addition, when assessing a low infestation level using a low threshold a larger plant sample size is required for sufficient accuracy (Allen, et al, 1972) and this may make scouting unpopular.

7.1.2.2 1981-82 season - As in the previous season, there was an overall yield response to spraying at all sites (Table 37). At Ukiriguru, the infestation was very low and none of the thresholds triggered spraying (Fig. 58a). At Lubaga, spraying on the threshold began 8 weeks after sowing and continued up to the 15th week (Fig. 58b). However, the critical period for spray treatment at this site occurred between week 8 and 12 when most of the thresholds triggered spraying (Fig. 58b). At Kisuke, the critical period appeared to have been between week 12 and 17 and also during week 21. However, the mean yield results obtained at this site suggest that the thresholds used were not low enough to trigger early season spraying which seemingly would have been more beneficial, at least on the routine treatment, than the late sprays which were applied on treatment B, C and D (Fig. 58c).

Overall, the results were variable between the sites but threshold A based on flared squares continued to give higher economic returns than the routine spraying treatment at the Lubaga site (Table 37(2)). Threshold A, (0.5 flared squares per plant) triggered four sprays at Lubaga and one at Kisuke. At Lubaga, this treatment outyielded all the other treatments including the calendar treatment

Table 37. Cost/benefit analysis of the seed cotton yields in relation to timing and numbers of spray applications in the 1981-82 season.

(1) Ukiriguru site:

Treatment	Mean yield kg/ha(%AR)	Number of sprays	Gross value of crop Tz.sh./ha	Cost of insecticide Tz.sh./ha	Total revenue Tz.sh. per ha
A	521(88)	0	2311	0	2311
B	535(88)	0	2373	0	2373
C	509(89)	0	2269	0	2269
D	490(90)	0	2195	0	2195
E	633(89)	5	2822	353	2469
F	533(87)	0	2353	0	2353
SE	±51.65				

Yield gain kg/ha
over unsprayed

% yield gain
unsprayed

E 100

18.7

(2) Lubaga site:

Treatment	Mean yield kg/ha(%AR)	Number of sprays	Gross value of crop Tz.sh./ha	Cost of insecticide Tz.sh./ha	Total revenue Tz.sh. per ha
A	2219(97)	4	10 283	282	10001
B	1854(98)	6	8 632	424	8208
C	1988(97)	6	9 212	424	8788
D	2070(95)	6	9 501	424	9077
E	2040(98)	6	9 498	424	9074
F	1539(95)	0	7 064	0	7064
SE	±91.85				

Table 37 (Continued)

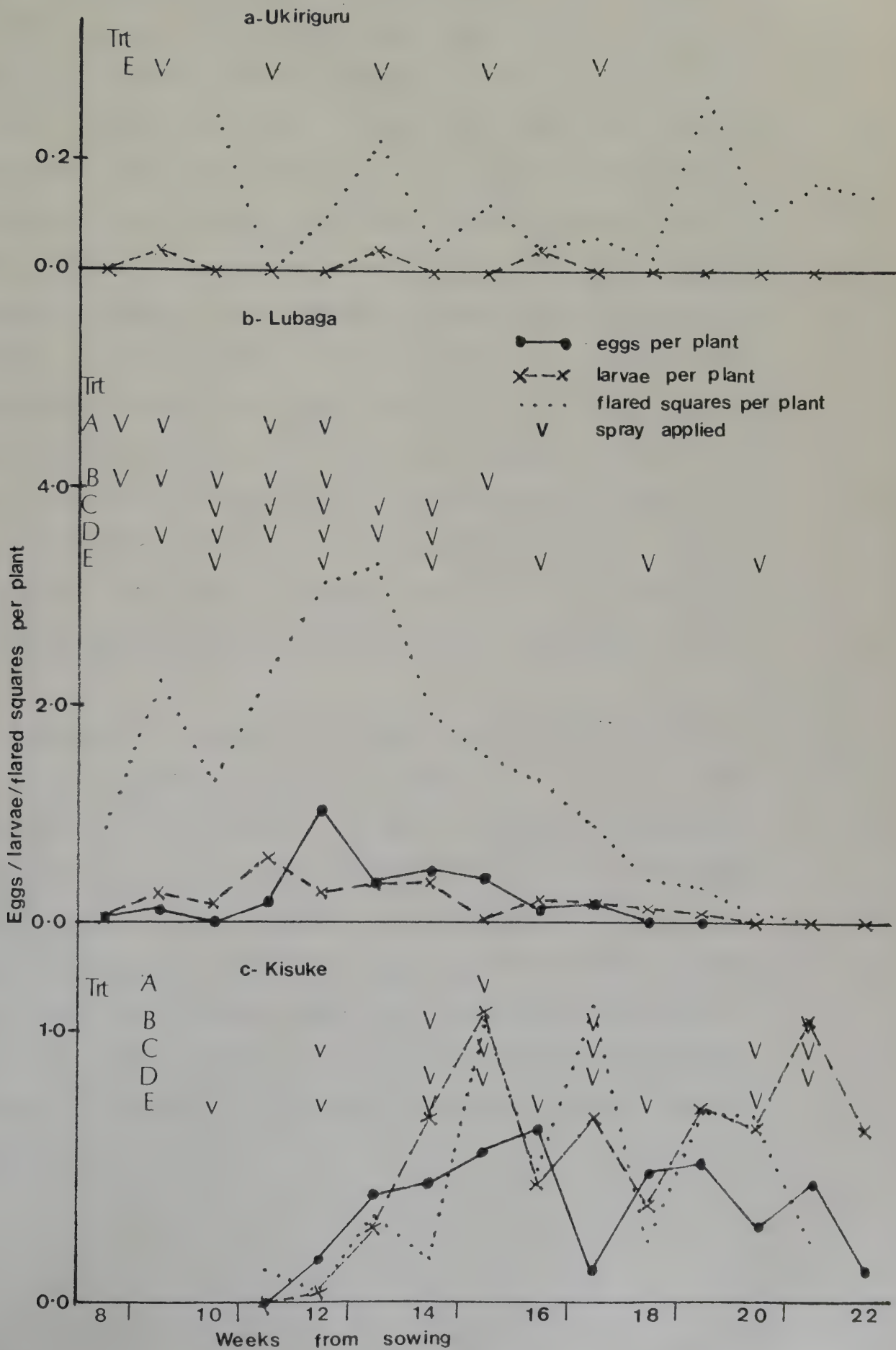
Treatment	Yield gain kg/ha over unsprayed	% yield gain over unsprayed	Monetary gain (+) or loss (-) over the routine regime Tz.sh./ha	%	Total revenue Tz.sh. per ha
A	680	44.2	+927	+10.2	3063
B	315	20.5	-866	- 9.5	3207
C	449	29.2	-289	- 3.2	3082
D	531	34.5	+ 3	+ 0.03	3191
E	501	32.5			4524
					1478

(3) Kisuke site:					
Treatment	Mean yield kg/ha(%AR)	Number of sprays	Gross value of crop Tz.sh./ha	Cost of insecticide Tz.sh./ha	Total revenue Tz.sh. per ha
A	686(94)	1	3134	71.0	3063
B	752(93)	3	3419	212.0	3207
C	752(94)	5	3435	353.0	3082
D	745(94)	3	3403	212.0	3191
E	1078(95)	6	4948	424.0	4524
F	340(84)	0	1478	0.0	1478
SE	+91.94				

Treatment	Yield gain kg/ha over unsprayed	% yield gain over unsprayed	Monetary gain (+) or loss (-) over the routine regime Tz.sh./ha	%
A	346	101.7	-1461	-32.3
B	412	121.1	-1317	-29.1
C	412	121.1	-1442	-31.8
D	405	119.1	-1333	-29.5
E	738	217.0		

Fig 58

The pattern and level of *H. armigera* infestation and damage on unsprayed cotton plots at Ukiriguru, Lubaga and Kisuke in 1981-82 showing spray timing on the sprayed plots



and the differences were significant at $P \leq 0.01$. This threshold was the most economic at the Lubaga site (Table 37(2)). However, at Kisuke, this threshold was significantly, $P \leq 0.01$, outyielded by the routine treatment, possibly because the infestation remained continuously below this threshold, which resulted in spray being applied too late to protect the bottom crop which usually gives the highest yield. Moreover, compared with the other spraying thresholds, treatment A gave the best economic return at Kisuke site because the net economic return achieved by one spray was considerable and relatively greater than that yield increase achieved by six routine sprays (Table 37(3)). Last season, treatment A was the most economic spraying threshold at Mwanhala and Ukiriguru. This season it was the most economic at Lubaga under conditions that were considered as a heavy H. armigera attack, and the best of the thresholds at Kisuke where a prolonged moderate infestation occurred.

Treatment B, also based on flared squares (0.4 flared squares per plant), triggered 6 sprays at Lubaga, five of them at weekly intervals except the last one (Fig. 58b). At this site treatment B was significantly outyielded by treatment A and the routine treatment (Table 37(2)). This threshold was probably too low and thus triggered excessive sprays. At Kisuke, this threshold triggered three sprays and marginally outyielded treatment A (Table 36(3)). The yield increase achieved by the two extra sprays initiated by threshold B compared to treatment A did not increase economic returns.

Treatment C, based on larvae and egg counts (0.3 eggs or 0.15 larvae per plant) triggered six sprays at Lubaga and five at Kisuke but failed to initiate a spray at Ukiriguru (Fig. 58). At Kisuke, spraying was based on larval counts whereas at Lubaga, five of the sprays were based on the egg threshold alone. At the latter site, the infestation was very high and the egg threshold triggered five sprays all at weekly intervals. However, it gave significantly less seed cotton yield than treatment A but was as good as the routine treatment. This threshold caused delayed spray timing at Lubaga possibly because the level of eggs and larvae remained well below the treatment level earlier on in the season, thus resulting in the loss of a part of the early crop. There is also a potential danger that the egg threshold which triggered five out of the six sprays can cause excessive spraying in a situation of a prolonged heavy attack. A higher egg threshold of 0.5 eggs per plant was evaluated at Ilonga on the Eastern Cotton growing area (ECGA) where the level of infestation was heavier and prolonged, but the results were disappointing. Thus, the threshold triggered more than one spray a week but the seed cotton yield was reduced and hence the net economic return was lower than with the routine regime of the ECGA. At Kisuke, where all sprayings were based on larval counts, treatment C gave lower economic return than the routine treatment. From the pattern of infestation at Kisuke, (Fig. 58c) it can be concluded that the threshold was too high and therefore led to delayed spraying and hence low crop yield. At Ilonga (ECGA) under a heavier and prolonged H. armigera infestation, a higher threshold of 0.2 larvae per plant was tried in the 1980-81 season. The seed cotton yield obtained was

low and it was concluded that this threshold was also too high, thus causing sprays to be applied either too late or too few to suppress significant damage (Hackett, 1982).

Spraying after the 18th week after sowing in WCGA would be economic only if the late rains are prolonged to produce a good top crop in April and May (Brown 1962). Thus, the sprays applied at Kisuke after week 19 (Fig. 58c) were wasted because the rains did not enable late formed fruits to mature. Timely sown cotton may lose its bottom crop to H. armigera attack early in the season but may compensate for it by producing a crop during the rains in April and May. The commercial cotton varieties grown in Tanzania are particularly suited to such compensatory growth, provided soil moisture and soil nutrients are not limiting. Matthews and Tunstall (1968) suggested that where crop lost early in the season cannot be replaced, the criterion for early season spray is a low level of infestation. Under an infestation pattern similar to Kisuke, a lower larval or egg threshold could have triggered earlier spraying and thus protected the bottom crop. However, at Ukiriguru, the net economic return obtained from the routine treatment was lower than that obtained from the unsprayed (Table 37(1)). In this situation, a lower threshold would not have paid dividends because rainfall was the most limiting factor for optimum plant growth and production at this site.

Treatment D (0.4 eggs plus larvae per plant) triggered six sprays at Lubaga all applied at weekly intervals and three at Kisuke

(Fig. 58b & c). At Kisuke, the spray interval initiated by this threshold could have been too long (too extended) to contain the H. armigera damage level which could have been occurring persistently at a low level (Fig. 58c). At Lubaga, this threshold was as good as the routine treatment.

Following these observations, there was a need to do more critical analysis of the relationship between the timing of spray application under different spraying thresholds and the overall level of damage. The scouting results and yield data for the period 1982-83 and 1983-84 seasons were used.

7.1.2.3. 1982-1983 season - The pattern of H. armigera damage timing is summarized in Fig. 59. The level of infestation was generally higher and much more prolonged at both sites than in the previous seasons.

At both sites, treatment A (0.5 or more flared squares per plant) triggered three sprays (Fig. 59a & b). At Ukiriguru this threshold was significantly ($P \leq 0.01$) outyielded by the routine treatment and also by threshold C (0.3 eggs or 0.10 larvae per plant) (Table 38(1)). Similarly, at Lubaga, treatment A gave significantly less seed cotton ($P = 0.05$), than treatment B (0.4 or more flared squares) and also significantly less ($P \leq 0.01$) than the routine treatment, so the net return from this threshold was the lowest at both sites (Table 38(1) & (2)).

Fig 59 The relationship between spray timing and the level of damage to cotton in 1982-83 season.

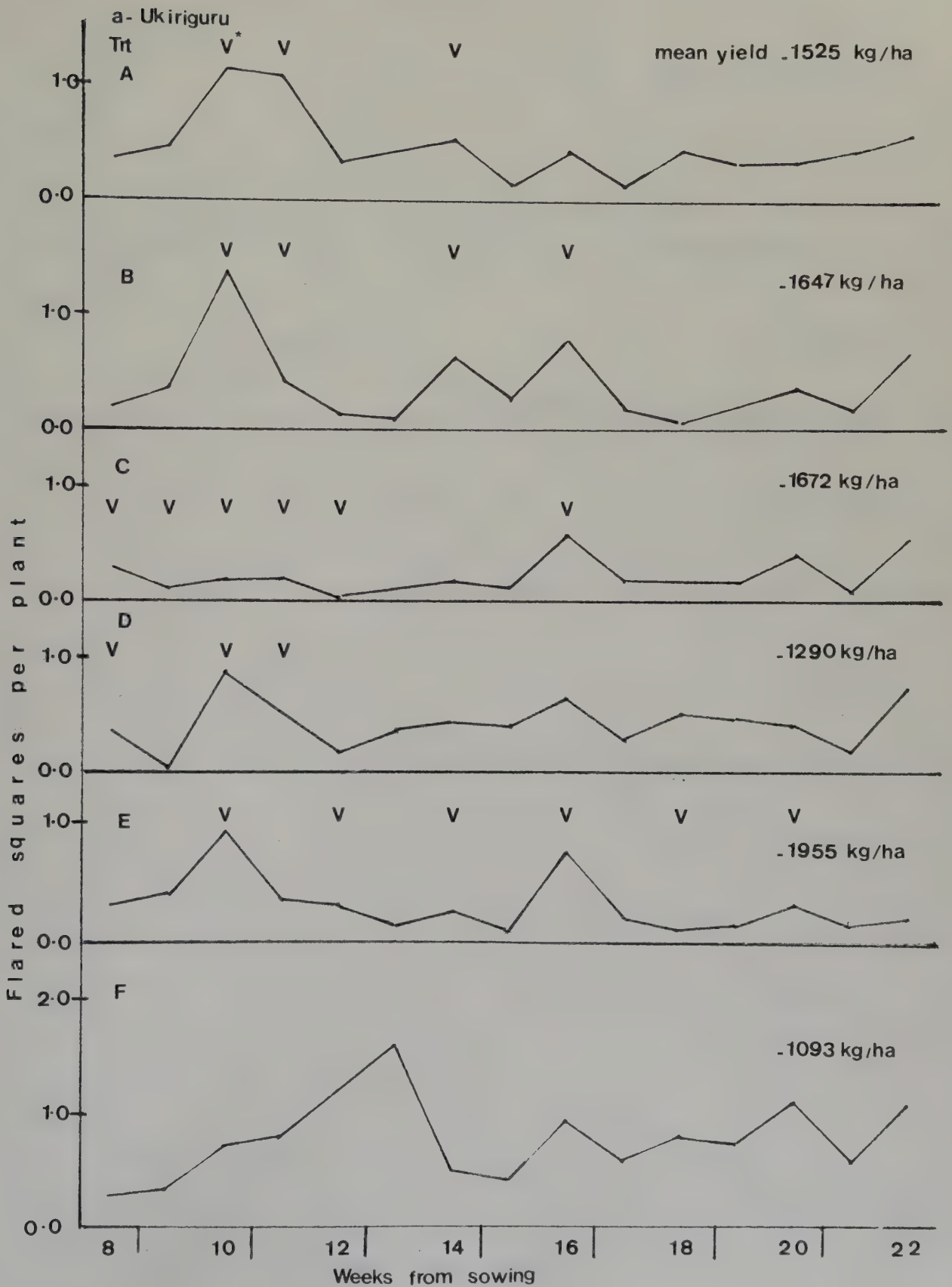
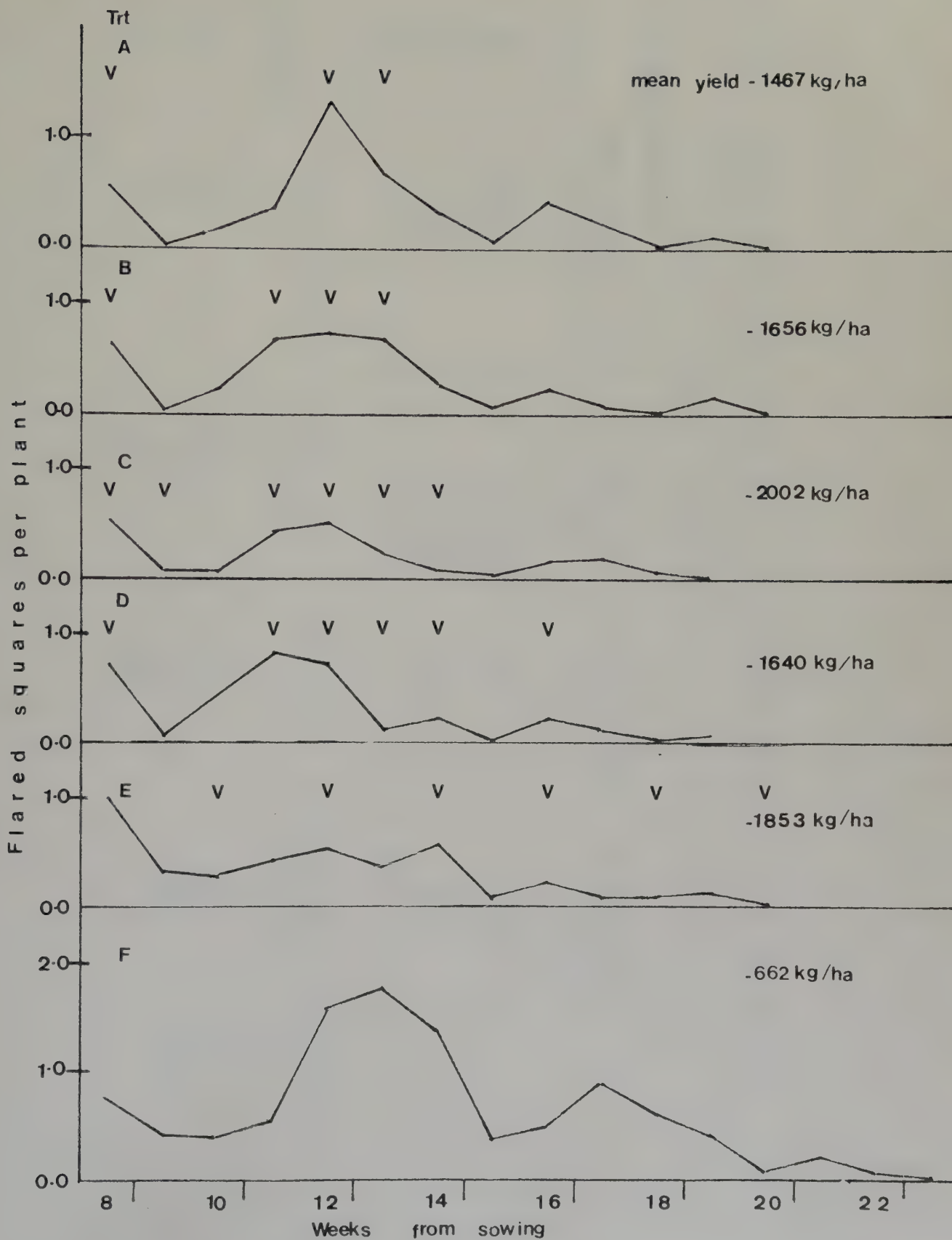


Figure 59 continued

b - Lubaga



V - spray applied

Table 38. Cost/benefit analysis of the seed cotton yields in relation to timing and numbers of spray applications in the 1982-83 season.

(1) Ukiriguru site:

Treatment	Mean number of of flared squares per plant	Number of sprays	Mean yield kg/ha (% AR)	Yield gain over unsprayed kg/ha	% yield gain over unsprayed
A	0.472	2	1525(84)	432	39.5
B	0.386	4	1647(83)	554	50.7
C	0.217	6	1672(83)	579	52.9
D	0.417	3	1290(79)	197	18.0
E	0.318	6	1955(87)	862	78.8
F	0.762	0	1093(83)		
SE			±72.7		
Treatment	Cost of insecticide Tz.sh./ha	Gross value of crop Tz.sh./ha	Total revenue Tz.sh./ha	Monetary gain (+) or loss (-) over the routine regime Tz.sh./ha	%
A	164	8467	8303	-2222	-21.1
B	329	9098	8769	-1756	-16.7
C	493	9336	8843	-1682	-15.9
D	247	6981	6737	-3788	-36.0
E	493	11018	10525		
F	0	6038	6038		

Table 38 (Continued)

(2) Lubaga site:

Treatment	Mean number of of flared squares per plant	Number of sprays	Mean yield kg/ha (% AR)	Yield gain kg/ha over unsprayed	% yield gain over unsprayed
A	0.273	3	1467(99)	805	121.6
B	0.236	4	1656(99)	994	150.1
C	0.148	6	2002(98)	1340	202.4
D	0.224	6	1640(99)	978	147.7
E	0.257	6	1853(99)	1191	179.9
F	0.630	0	662(97)		
SE			±93.9		
Treatment	Cost of insecticide Tz.sh./ha	Gross value of crop Tz.sh./ha	Total revenue Tz.sh./ha	Monetary gain (+) or loss (-) over the routine regime Tz.sh./ha	%
A	247	8761	8514	-2059	-19.5
B	329	9889	9560	-1013	- 9.6
C	493	11900	11407	+834	+ 7.9
D	493	9794	9301	-1272	-12.0
E	493	11066	10573		
F	0	3916	3916		

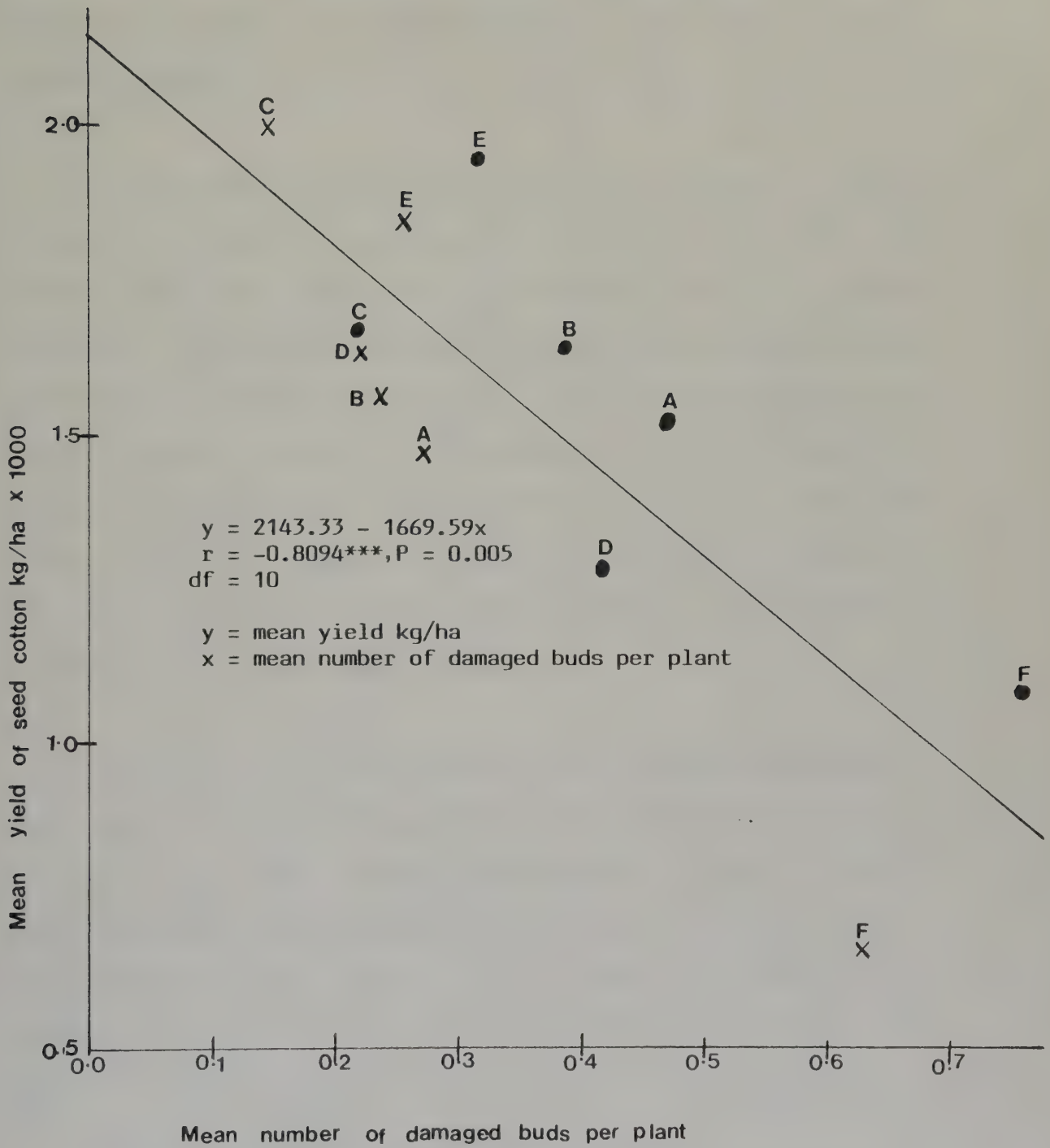
Treatment B, based on 0.4 flared squares, triggered 4 sprays at both sites (Fig. 59a & b). At Ukiriguru this treatment was significantly ($P < 0.01$) outyielded by the routine treatment but was statistically equal to thresholds A and C. At Lubaga, although threshold B outyielded treatment A and the differences were significant at $P < 0.05$, treatment B gave a significantly lower yield compared to the routine regime and also treatment C (Table 38(2)).

Treatment C (0.3 eggs or 0.10 larvae per plant) triggered six sprays at both sites. At Ukiriguru, apart from the first two sprays when the larvae and egg threshold was reached, the rest of the sprays were triggered by the larval counts. This treatment gave significantly more seed cotton than treatment A and D but was significantly ($P = 0.01$) outyielded by the routine treatment (Table 38(1)). At Lubaga, four of the sprays were triggered by egg count alone and the remaining two by both the egg and larval counts. At this site, this threshold gave the highest yield of seed cotton and gave a significantly higher yield ($P \leq 0.01$) than treatment D and B.

Treatment D triggered three sprays at Ukiriguru and six at Lubaga (Fig. 59a & b). At Ukiriguru, treatment D gave the lowest yield of seed cotton and was significantly outyielded by the other treatments and the net return was thus the lowest (Table 38(1)). At Lubaga, this treatment was significantly outyielded by the routine treatment at $P = 0.05$ and by threshold C at $P = 0.01$.

The overall net return analysis (Table 38) indicates that

Fig 60 The relationship between the mean level of damage and the mean yield of seed cotton kg/ha for Ukiriguru and Lubaga sites 1982-83 season



● Ukiriguru

× Lubaga

treatment C, the egg and larval threshold, was the most profitable. However, at Ukiriguru, the routine treatment gave a higher economic return (Table 38(1)).

The relationship between mean yield and mean level of damage during the season for both sites is summarized in Figure 60. Overall, there was a significant yield decline as the level of damage increased, and therefore a lower damage threshold, possibly lower than the 0.4 damaged buds threshold, could have triggered more optimal sprays. Treatment C which used a very low infestation threshold suffered less damage compared to the other thresholds (Table 38) and gave higher yield gain over the unsprayed compared to the other thresholds at both sites and a higher yield than the routine spray at Lubaga (Table 38(2)).

The overall poor performance of the threshold treatments is partly because the level of infestation and/or damage often remained persistently just below the spraying threshold and since no control measure was taken, damage continued to accumulate. Low damage over a prolonged period can lead to a heavier total crop loss, as in treatments A and D at Ukiriguru and treatments A at Lubaga (Fig. 38a & b).

7.1.2.4. 1983-84 season - The level of H. armigera infestation and damage was very heavy at Ukiriguru and Mwanhala sites, moderate at Mabuki and light at Lubaga. At all the sites, the main peak of infestation and damage occurred between the 10th week and 20th week

Table 39. Cost/benefit analysis of the seed cotton yields in relation to timing and numbers of spray applications in the 1983-84 season.

(1) Ukiriguru site:

Treatment	Mean number of of flared squares per plant	Number of squares sprays	Mean yield kg/ha (% AR)	Yield gain kg/ha over unsprayed	% yield gain over unsprayed
A	0.258	3	1502(97)	370	32.7
B	0.270	3	1435(95)	303	26.8
C	0.249	5	1708(98)	576	50.9
D	0.476	0	1132(95)		
SE			±66.0		
Treatment	Cost of insecticide Tz.sh./ha	Gross value of crop Tz.sh./ha	Total revenue Tz.sh./ha	Monetary gain (+) or loss (-) over the routine regime Tz.sh./ha	
A	272	12155	11883	-1416	-10.6
B	272	11481	11209	-2090	-15.7
C	452	13751	13299		
D	0	9271	9271		

(2) Lubaga site:

Treatment	Mean number of of flared squares per plant	Number of squares sprays	Mean yield kg/ha (% AR)	Yield gain kg/ha over unsprayed	% yield gain over unsprayed
A	0.121	1	974(93)	288	42.0
B	0.147	1	952(97)	266	38.8
C	0.102	6	1123(99)	437	63.7
D	0.217	0	686(93)		
SE			±57.1		

Table 39 (Continued)

(2) Lubaga site (continued)

Treatment	Cost of insecticide Tz.sh./ha	Gross value of crop Tz.sh./ha	Total revenue Tz.sh./ha	Monetary gain (+) or loss (-) over the routine regime Tz.sh./ha %
A	91	7798	7707	-555 -6.7
B	91	7788	7697	-565 -6.8
C	544	8806	8262	
D	0	5561	5561	

(3) Mabuki site:

Treatment	Mean number of of flared squares per plant	Number of sprays	Mean yield kg/ha (% AR)	Yield gain kg/ha over unsprayed	% yield gain over unsprayed
A	0.177	1	706(96)	126	21.7
B	0.126	1	779(97)	199	34.3
C	0.100	6	950(97)	370	63.8
D	0.147	0	580(95)		
SE			±64.9		

Treatment	Cost of insecticide Tz.sh./ha	Gross value of crop. Tz.sh./ha	Total revenue Tz.sh./ha	Monetary gain (+) or loss (-) over the routine regime Tz.sh./ha %
A	91	5721	5630	-1142 -16.8
B	91	6354	6263	-509 -7.5
C	544	7316	6772	
D	0	4750	4750	

Table 39 (Continued)

(4) Mwanhala site:

Treatment	Mean number of of flared squares per plant	Number of sprays	Mean yield kg/ha (% AR)	Yield gain kg/ha over unsprayed	% yield gain over unsprayed
A	0.298	5	1043(98)	714	217.0
B	0.258	6	1171(98)	842	255.9
C	0.250	5	1111(97)	782	237.7
D	0.728	0	329(75)		
SE					

Treatment	Cost of insecticide Tz.sh./ha	Gross value of crop Tz.sh./ha	Total revenue Tz.sh./ha	Monetary gain (+) or loss (-) over the routine regime Tz.sh./ha	%
A	453	8191	7738	-518	-6.3
B	544	9158	8614	+358	+4.3
C	453	8709	8256		
D	0	2418	2418		

Fig 61 The relationship between spray timing and the level of damage to cotton in 1983-84 season.

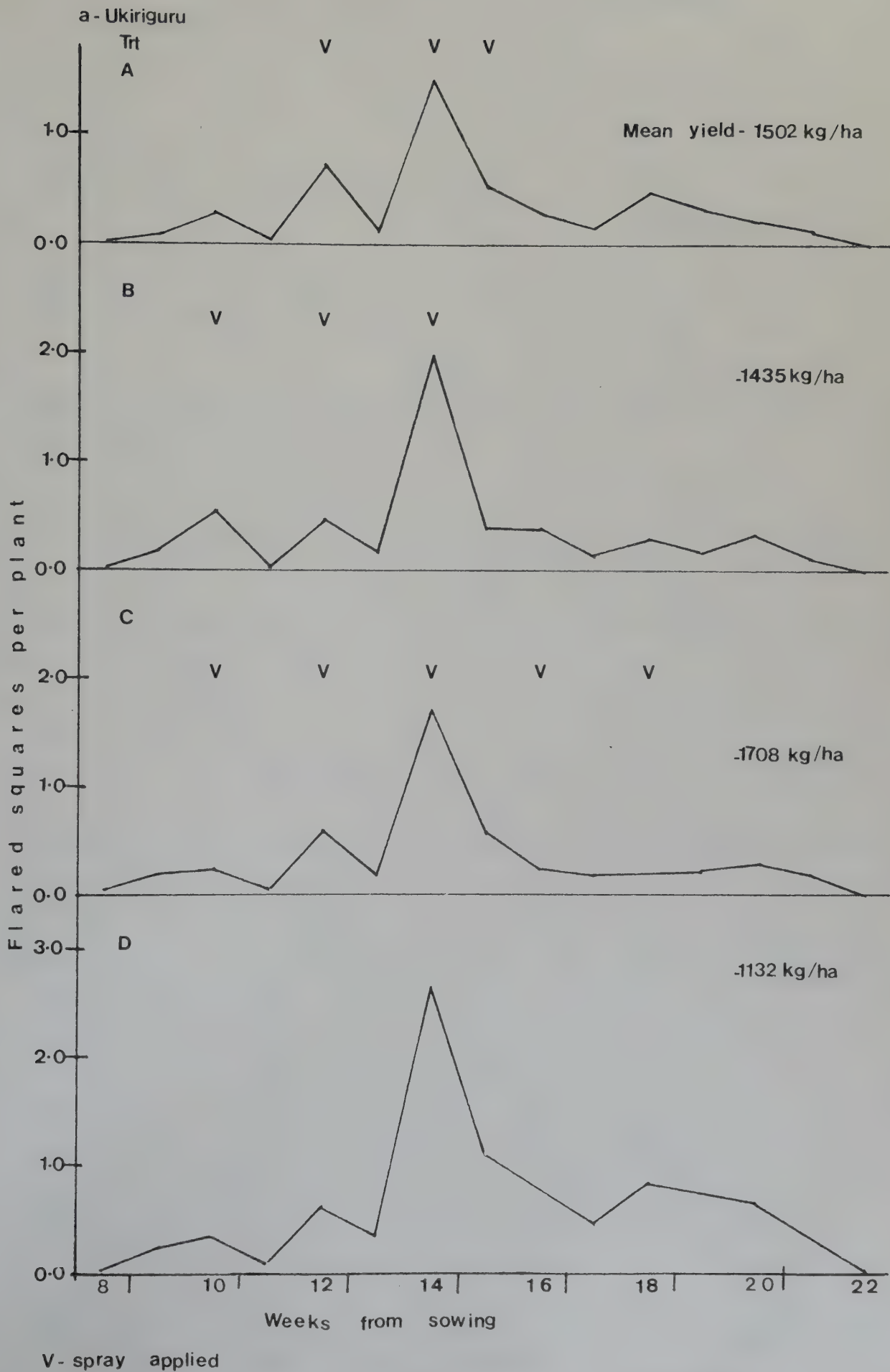


Figure 61 continued

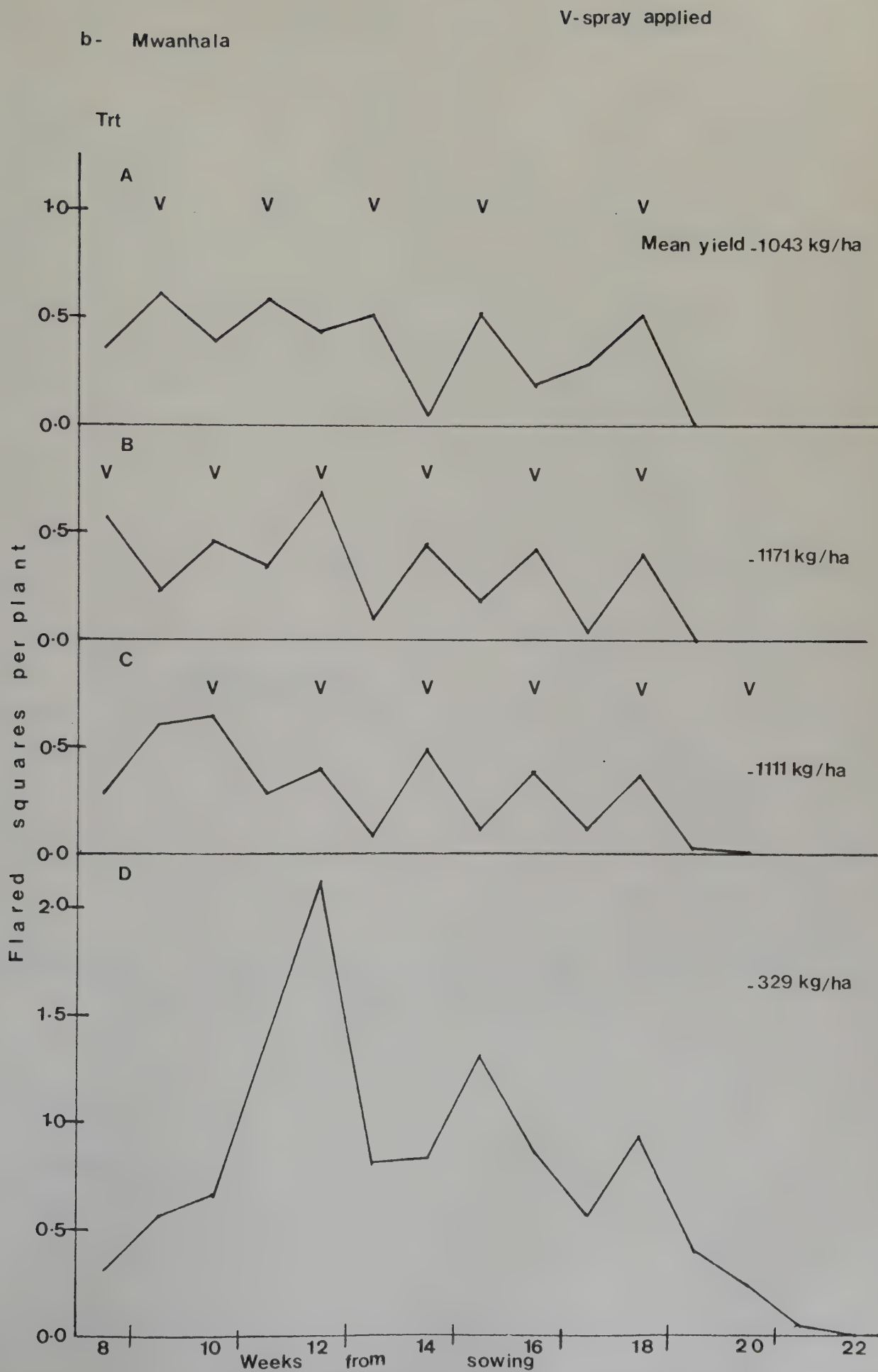
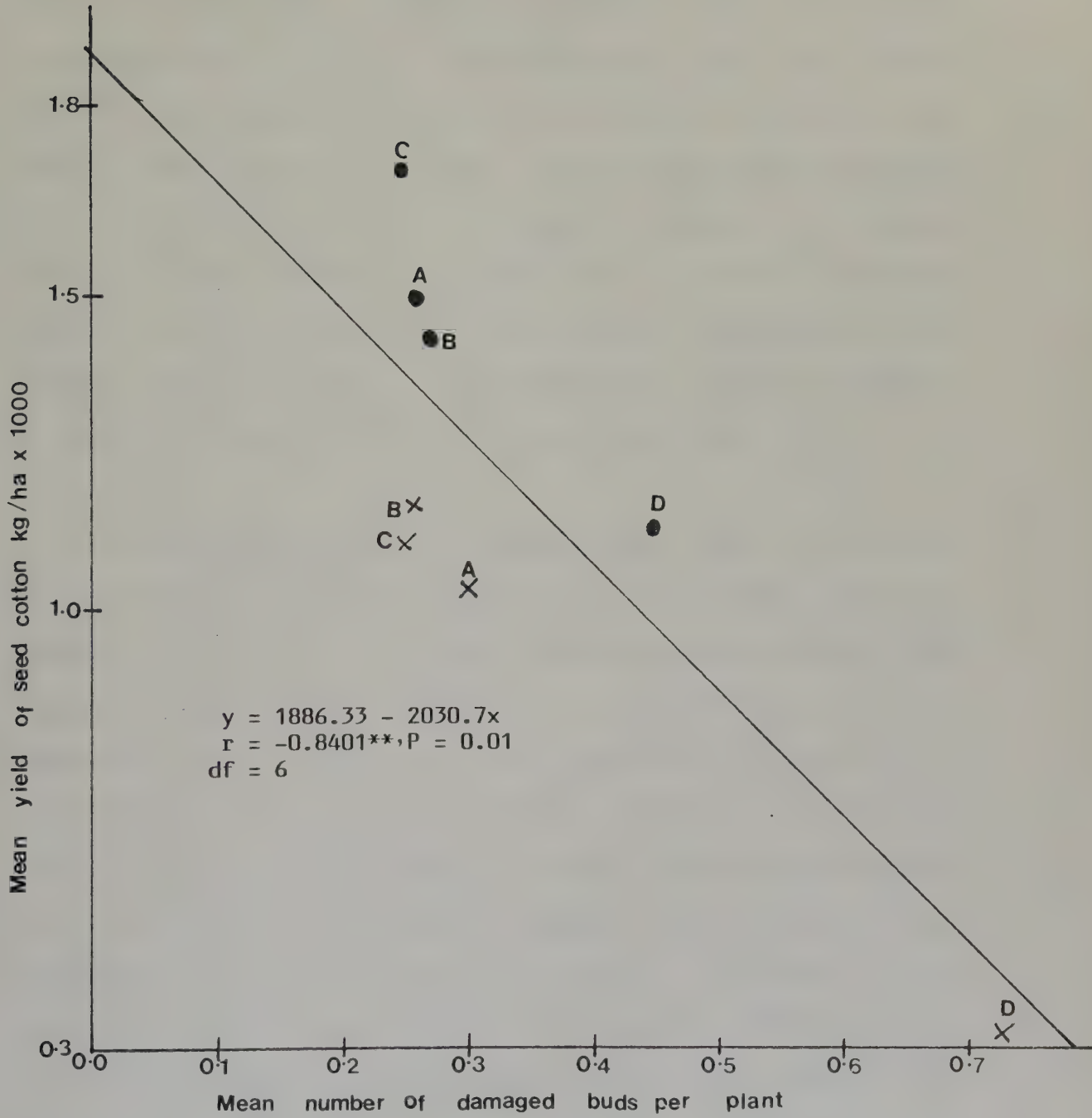


Fig 62 The relationship between the mean level of damage and the mean yield of seed cotton kg/ha for Ukiriguru and Mwanhala sites 1983-84 season.



● Ukiriguru

X Mwanhala

after sowing and none of the thresholds triggered spraying before the 10th week particularly at Ukiriguru and Mwanhala (Fig. 61a & b) the two sites where the level of infestation was high. There was an overall high response to spraying at the Mwanhala site than at the rest of the other sites (Table 39). However, the routine treatment gave an overall higher yield response to spraying at Ukiriguru, Mabuki and Lubaga than at Mwanhala (Table 39). At Ukiriguru and Mabuki, the routine treatment gave significantly higher yield of seed cotton ($P = 0.01$) and ($P = 0.05$) respectively, than the threshold treatments and thus gave higher economic returns (Table 39(1)).

The relationship between the seasonal mean level of damage and the mean yield of seed cotton for Ukiriguru and Mwanhala is shown in Fig. 62. At both sites, the overall mean level of damage between the sprayed treatments did not appear to be significantly different (Table 39(1) & (4)). However, it is the seasonal fluctuations under the different spraying treatments which contribute to the final yield. Thus, at Ukiriguru the extra sprays applied in weeks 16 and 18 (Fig. 61a) on the routine treatment might have caused a substantial yield increase relative to the other treatments. As in the previous season, the inadequacy in the spraying thresholds used seem to be the failure to trigger optimal sprays largely because they have been too high. Thus, on both thresholds A and B at Ukiriguru site the percent level of damaged squares between weeks 16, 17 and 18 (Fig. 61a) remained persistently just below the threshold and this may have resulted in significant yield loss. Similarly, at Mwanhala treatment A might have caused a significant yield increase if a spray

was applied at week 17 because the proportion of damaged squares also remained persistently just below the threshold in weeks 16 and 17 (Fig. 61b).

In summary, the results obtained in 1982-83 and 1983-84 seasons indicated that the thresholds used had failed to trigger optimum sprays and thus gave lower economic returns compared to the routine treatments because under conditions of low but persistent infestation levels, significant yield losses occurred. Thus, the thresholds needed modifications to accommodate situations of persistent low levels of damaged squares. Hence, the trial in 1984-85 season was modified accordingly.

7.1.2.5. 1984-85 season - Overall, the H. armigera infestation and damage level was very heavy at Ukiriguru, moderate at Lubaga and very light at Mabuki.

There was an overall sharp significant yield increase at all the sites as a result of using flexible spraying thresholds as compared to the fixed spraying treatment levels (Fig. 63 and 64a to c). These results provided a good evidence to the fact that a flexible treatment threshold can trigger relatively more optimal spraying and thus minimize losses due to the pest damage. The 0.5 H. armigera damaged buds or flowers per plant per count or in two consecutive counts treatment gave an overall higher yield of seed cotton and economic return than the other threshold treatments at two out of the three sites (Table 40(1) & (2)).

Fig 63 The relationship between the mean level of damage and the mean yield of seed cotton kg/ha for Ukiriguru, Mabuki and Lubaga sites 1984-85 season.

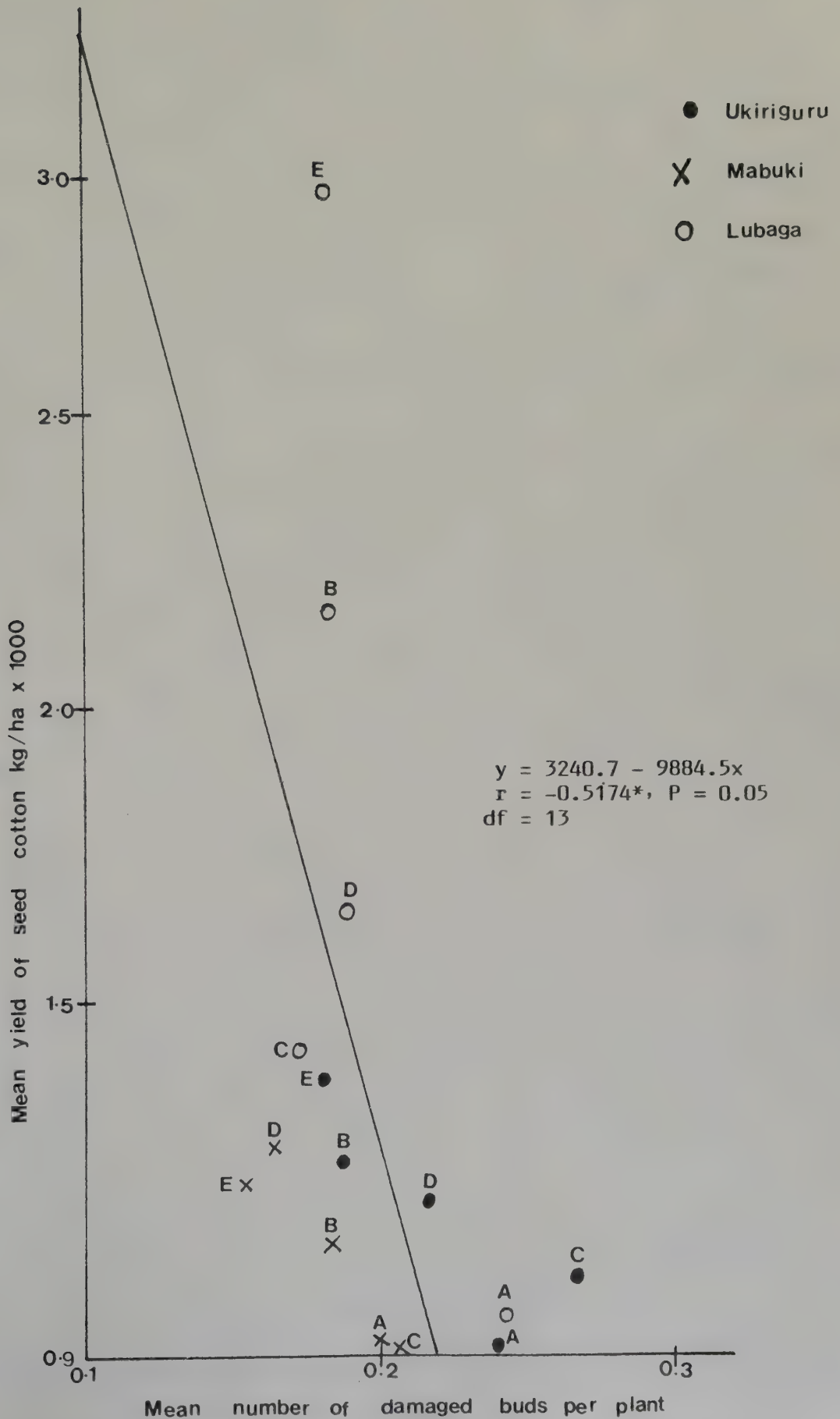


Fig 64 The relationship between spray timing and the level of damage to cotton in 1984-85.

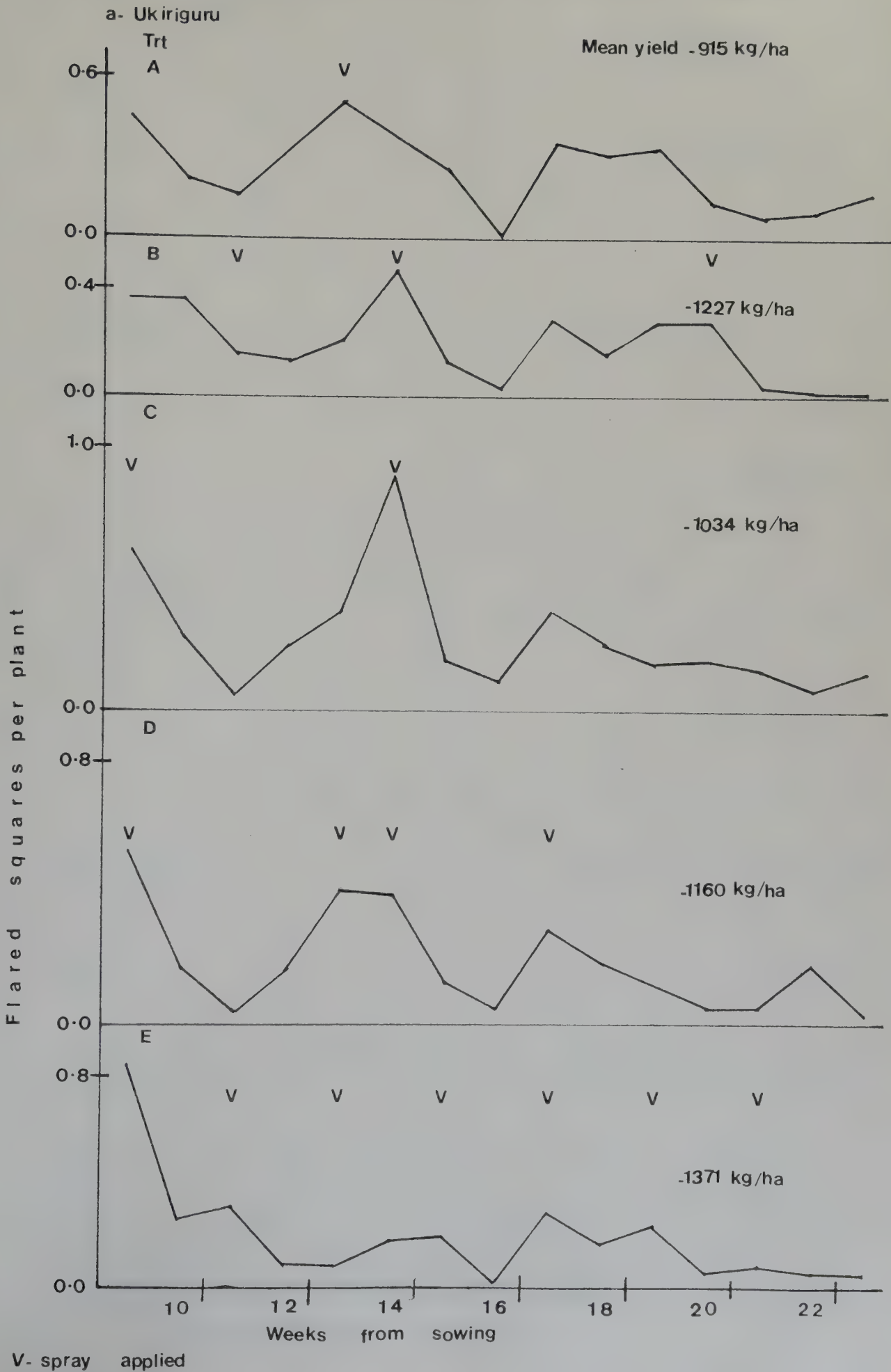


Figure 64 continued

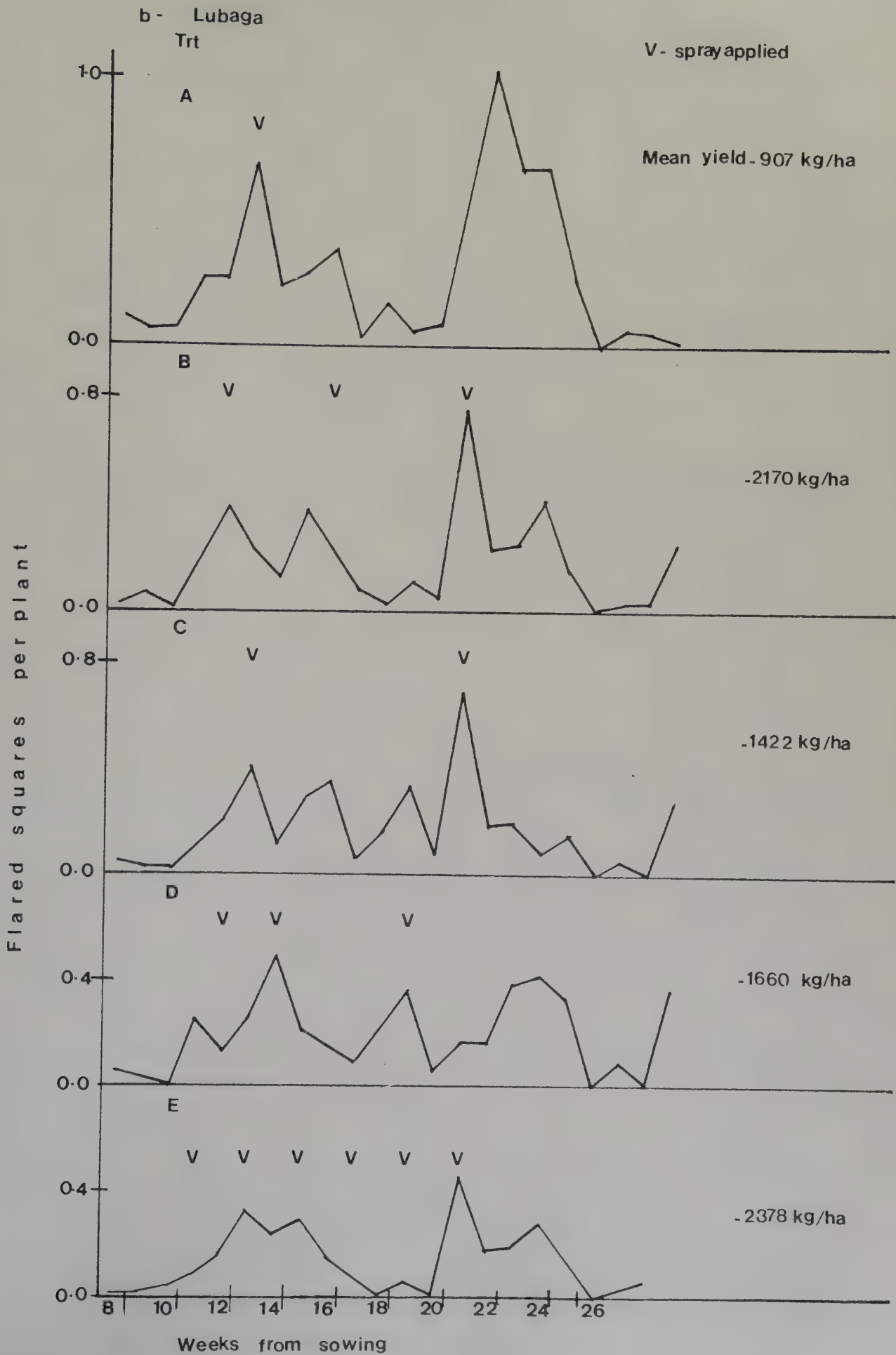


Figure 64 continued

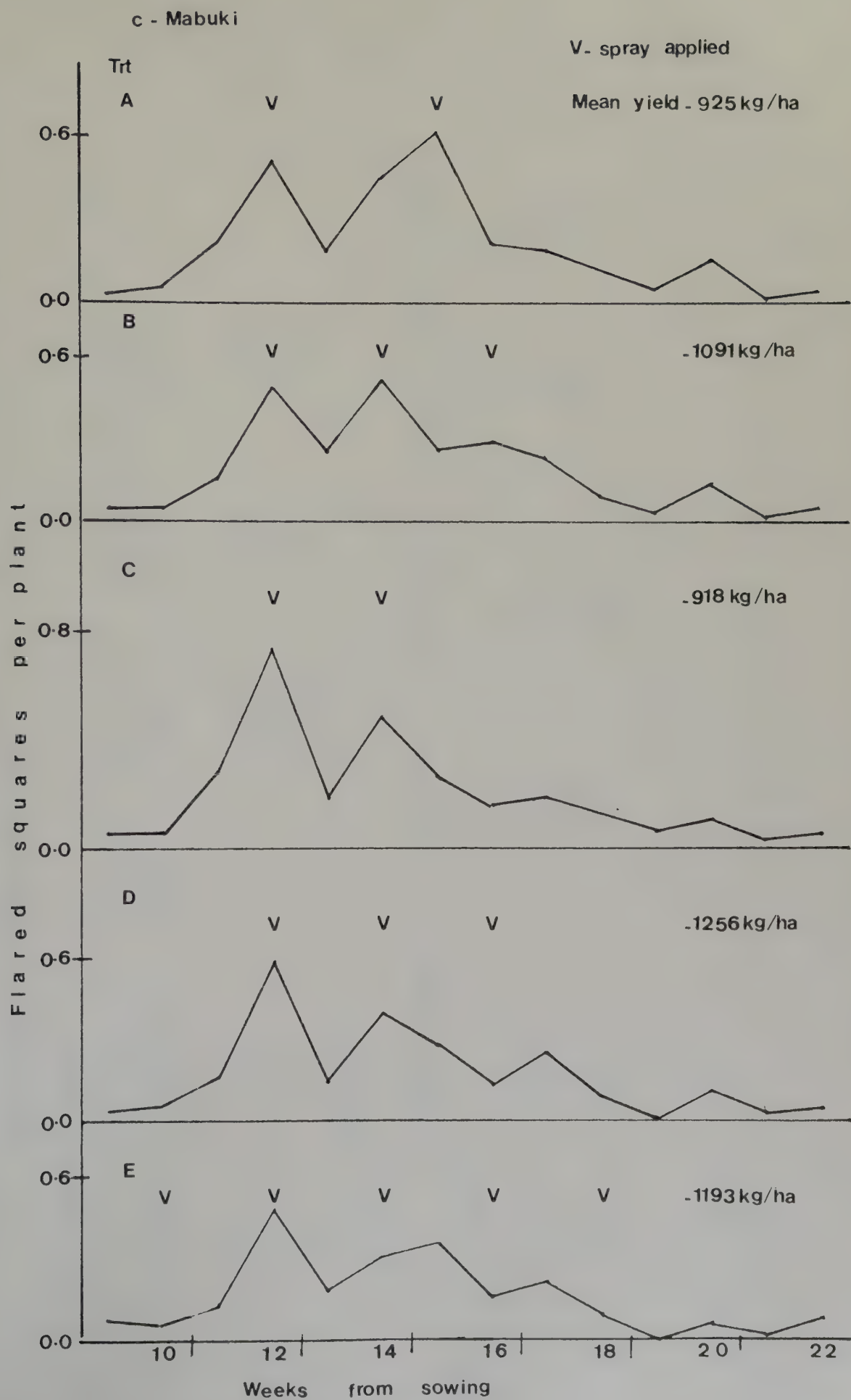


Table 40. Cost/benefit analysis of the seed cotton yields in relation to timing and numbers of spray applications in the 1984-85 season.

(1) Ukiriguru site:

Treatment	Mean number of flared squares per plant	Number of sprays applied	Mean yield kg/ha (%AR)	Yield gain (+) or loss (-) over the routine regime kg/ha	Yield gain (+) or loss (-) over the routine regime %
A	0.240	1	915(83)	-456	-33.2
B	0.186	3	1227(87)	-144	-10.5
C	0.267	2	1034(86)	-327	-24.6
D	0.217	4	1160(84)	-211	-15.3
E	0.182	6	1371(87)		
SE of treatments			±57.5		
Unsprayed			1117(86)		

Treatment	Cost of insecticide Tz.sh./ha	Gross value of crop Tz.sh./ha	Total revenue Tz.sh./ha	Monetary gain (+) or loss (-) over the routine regime Tz.sh./ha	Monetary gain (+) or loss (-) over the routine regime %
A	180	11395	11215	-4250	-27.5
B	539	15228	14689	- 776	- 5.1
C	359	12876	12517	-2948	-19.1
D	719	14013	13294	-2171	-14.4
E	1078	16539	15465		

Table 40 (Continued)

(1) Ukiriguru site: (continued)

Thresholds comparisons:

a) Threshold B vs A				
	Yield gain kg/ha	% yield gain	Revenue gain Tz.sh./ha	% Revenue gain
	+312	+34.1	+3474	30.9
b) Threshold D vs C				
	Yield gain kg/ha	% yield gain	Revenue gain Tz.sh./ha	% Revenue gain
	+126	+12.2	+ 777	+ 6.2

(2) Lubaga site:

Treatment	Mean number of flared squares per plant	Number of sprays applied	Mean yield kg/ha (%AR)	Yield gain (+) or loss (-) over the routine regime kg/ha	%
A	0.263	1	907(84)	-1971	-68.5
B	0.184	3	2170(84)	- 708	-24.6
C	0.174	2	1422(87)	-1456	-50.6
D	0.190	3	1660(86)	-1218	-42.3
E	0.183	6	2878(90)		
SE of treatments			±97.7		
Unsprayed			1085(89)		

Table 40 (Continued)

(2) Lubaga site (continued):

Treatment	Cost of insecticide Tz.sh./ha	Gross value of crop Tz.sh./ha	Total revenue Tz.sh./ha	Monetary gain (+) or loss (-) over the routine regime Tz.sh./ha %
A	180	11339	11159	-24099 -68.3
B	539	27562	27023	-8235 -23.3
C	359	17914	17555	-17703 -50.2
D	539	20709	20170	-15088 -42.8
E	1078	36336	35258	

Thresholds comparisons:

a) Threshold B vs A

Yield gain kg/ha	% Yield gain	Revenue gain Tz.sh./ha	% Revenue gain
+1263	+139.2	+15864	+142.1

b) Threshold D vs C

Yield gain kg/ha	% Yield gain	Revenue gain Tz.sh./ha	% Revenue gain
+238	+16.7	+2616	+14.9

Table 40 (Continued)

(3) Mabuki site:

Treatment	Mean number of flared squares per plant	Number of sprays applied	Mean yield kg/ha (%AR)	Yield gain (+) or loss (-) over the routine regime kg/ha %	Monetary gain (+) or loss (-) over the routine regime Tz.sh./ha %
A	0.200	2	925(94)	-268	-22.5
B	0.184	3	1091(96)	-102	- 8.5
C	0.207	2	918(93)	-275	-23.0
D	0.165	3	1256(94)	+ 63	+ 5.3
E	0.157	5	1193(95)		
SE of treatments			±59.7		
Unsprayed			366(68)		
Treatment	Cost of insecticide Tz.sh./ha	Gross value of crop Tz.sh./ha	Total revenue Tz.sh./ha	Monetary gain (+) or loss (-) over the routine regime Tz.sh./ha %	
A	359	11850	11491	-2518	-17.9
B	539	13971	13432	- 577	- 4.1
C	359	11712	11353	-2656	-18.9
D	539	16040	15501	+1492	+10.6
E	899	14908	14009		

Thresholds comparisons:

a) Threshold B vs A	Yield gain kg/ha +139	% yield gain +15.0	Revenue gain Tz.sh./ha +1941	% Revenue gain +16.9
b) Threshold D vs C	Yield gain kg/ha +338	% yield gain +36.8	Revenue gain Tz.sh./ha +4148	% Revenue gain +36.5

At Ukiriguru, seed cotton yield treatment differences were significant at $P \leq 0.01$. The routine treatment was the best and gave significantly higher yield and economic returns compared to the other treatments (Table 40(1)). However, treatment B (0.5 damaged buds or flowers per plant per count or in two consecutive counts) gave significantly higher yield and higher percent revenue than treatment A ($P < 0.01$) and C ($P < 0.05$). Similarly, treatment D (0.4 damaged buds or flowers per plant per count or in two consecutive counts) gave significantly ($P < 0.05$) more yield and economic return than treatment C. Treatments B and D were statistically equal, but overall, B gave higher yield response and revenue compared to the other treatment thresholds (Table 40(1)).

At Lubaga, treatment yield differences were also significant at $P \leq 0.01$. The routine treatment gave the highest yield of seed cotton and was significantly ($P \leq 0.01$) superior to the other treatments (Table 40(2)). Of the treatment thresholds, B was the best and significantly ($P \leq 0.01$) outyielded the others. Treatment B gave 142.1 percent and 24.8 percent more revenue than treatments A and D respectively (Table 40(2)). Treatment D was also superior to C and gave significantly ($P < 0.05$) higher yield and 14.9 percent more revenue than treatment C (Table 40(2)).

At Mabuki, the treatment yield differences were significant at $P \leq 0.05$. Treatments A and C gave significantly lower yield of seed cotton compared to the other treatments (Table 40(3)). Treatment D gave the highest yield and was significantly ($P = 0.05$) better than

treatment B and ($P \leq 0.05$) better than treatments A and C. However, the routine treatment was statistically as good as treatments B and C. Overall, treatment B was significantly superior ($P \leq 0.05$) to treatment A and gave 16.9 percent more revenue compared to treatment A (Table 40(3)).

7.1.2.6. Summary of the scouting trial results 1980-81 to 1984-85 season - Strategies for spraying at different levels of H. armigera infestation and for defining damage thresholds were assessed in comparison with current spraying regime. The results were often inconsistent between sites and seasons. Overall, the routine spraying regime gave higher yields of seed cotton and higher net returns compared with the threshold strategies used. The thresholds used in these trials were either too high or too low to initiate a spray application programme that compared favourably with routine spraying. Where the threshold was too high, yield loss often occurred because bud damage at a low but persistent level was left unchecked and this constituted an economic crop loss (Table 37(3) Treatments A and C). In contrast, where the threshold was too low there was a tendency to apply excessive sprays and the final cotton yields could not justify the overall increased costs of spraying (Table 37(2) Trt B). Thus, there is a need to do more research to identify optimum spraying thresholds under the conditions in WCGA.

In conclusion, the study has shown that:-

- a) Cotton spraying in WCGA is economically beneficial in most seasons (Table 41).

Season	Site	Yield of seed cotton kg/ha (%AR)		Response to spraying kg/ha	%	Gross value of crop Tz.sh. per ha (using 84-85 prices)		Cost of insecti- cide (using 84-85 prices)	Net revenue of crop Tz.sh./ha		Revenue gain over unsprayed Tz.sh/ha %
		6 sprays (5)	Unsprayed			Sprayed	Unsprayed		Sprayed	Unsprayed	
1980-81	Ukiriguru	722(94)	431(91)	291	67.5	9530	5624	899	8631	3007	53.5
	Lubaga	1295(89)	1078(85)	217	20.1	16770	13744	1078	15692	1948	14.2
	Mwanhala	1067(84)	740(84)	327	44.2	13551	9398	1078	12473	3075	32.7
1981-82	Ukiriguru	633(87)	518(88)	115	22.2	8134	6682	899	7235	553	8.2
	Lubaga	2040(98)	1539(95)	501	32.5	27336	20392	1078	26258	5866	28.8
	Kisuke	1078(95)	340(84)	738	217.0	14283	4318	1078	13205	8887	205.8
1982-83	Ukiriguru	1955(87)	1093(83)	862	78.8	25122	13826	1078	24044	10218	73.9
	Lubaga	1853(99)	662(97)	1191	179.9	24923	8838	1078	23845	15007	169.8
1983-84	Ukiriguru	1708(98)	1132(95)	576	50.9	22887	14999	899	21988	6989	46.6
	Lubaga	1123(99)	686(93)	437	63.7	15104	9021	1078	14026	5005	55.5
	Mabuki	950(97)	580(95)	370	63.8	12682	7685	1078	11604	3919	51.0
	Mwanhala	1111(97)	329(75)	782	237.7	14832	4030	899	13933	9903	245.7
1984-85	Ukiriguru	1371(87)	1117(86)	254	22.7	17617	14298	1078	16539	2241	15.7
	Lubaga	2878(90)	1085(89)	1793	165.2	37414	14051	1078	36336	22285	158.6
	Mabuki	1193(95)	366(68)	827	225.9	15807	4355	899	14908	10553	242.3
Mean		1398.5	779.7	618.8	79.4						
SE		±590.53	±369.99								

Table 41. Overall comparison of the mean yield of seed cotton response to the routine spraying to unsprayed cotton in WCGA 1980-81 to 1984-85 seasons.

- b) Scouting may not necessarily reduce the number of insecticide applications in a season but rather can assist in fine tuning and thus optimise the benefits from spraying (Table 37(2) Trt C & D; Table 38(2) Trt C; Table 39(4)).
- c) There were large variations between sites (in the same season) and seasons (at the same sites) in the level and timing of H. armigera infestation and damage on cotton in WCGA. Consequently the response to spraying is likely to vary between areas and seasons (Table 41). However, the critical period for scouting in most seasons appear to be between the 8th to 20th weeks after sowing (Figs. 57, 58, 59, 61 and 64).
- d) There is scope to improve the routine spraying regime. Although the thresholds used did not give an overall higher yield of seed cotton and economic returns compared to the routine regime, there were occasions when the thresholds gave equal or higher seed cotton yield results and economic returns than the routine regime (Table 36(2), 37(2), and 38(2). In some instances, one or two properly timed sprays gave higher yield responses to spraying than the six routine applications (Table 36(2) and (3) and 39(2)).
- e) Threshold spraying strategy can lead to insecticide saving in a season when the level of infestation and damage remain persistently very low and thus does not justify spraying (Table 37(1)).
- f) Occasionally, the H. armigera damage level will not reach 0.5 damaged buds per plant at any particular count but will remain just below the 0.5 damage threshold level over several counts.

If the situation is left uncontrolled, the cumulative damage level will lead to economic yield loss, and chemical treatment will be inevitable to avoid such losses (Matthews and Tunstall, 1968). So, a flexible threshold strategy could be adopted which enables a farmer to spray when a certain level of damage is reached per plant per count or when a lower level is reached on each of two consecutive counts. This is likely to give higher yield responses and economic returns than a fixed threshold which requires spraying to be done when the same damage level per plant per count is reached (Table 40).

As mentioned earlier, many farmers in WCGA do not follow the routine spraying recommendation and some farmers conduct crude 'scouting' before deciding to spray. Thus, although the results from the series of trials have not been able to identify an optimum treatment threshold, it is considered necessary to provide a rough guideline to the farmers pending further improvement. From the trend of results, the 0.5 damage threshold have given overall less revenue losses compared to the routine spraying regime and higher revenue gain than the other thresholds (Tables 36(2), 37(2), 39(1) and (2)). Furthermore, when this threshold was modified and made more flexible (0.5 damaged buds per plant per count or in two consecutive counts) there was a large significant yield increase and higher economic return, and thus compared more favourably to the routine spraying regime (Table 40) than the other thresholds. Thus, it is suggested that, the farmers who would like to scout their crops for damage before spraying, should spray when the damage level is 0.5 flared

squares per plant per count in a week or 0.5 total flared squares in two consecutive counts. A lower threshold has been purposely avoided to minimize sampling error and the danger of applying unnecessary insecticide sprays.

8 GENERAL DISCUSSIONS AND IMPLICATIONS TO IMP WITH EMPHASIS ON COTTON

8.1 Effect of climatic factors on *H. armigera* population changes

Temperature, rainfall, relative humidity, wind and sunshine are all aspects of weather which can have significant impact on the population changes of an insect (Williams, 1940; Haggis, 1981). In this study, rainfall was found to be an important factor which had both direct and indirect relationships with the incidence of *H. armigera* on its alternative hosts. Adequate and well distributed rainfall was often associated with heavy to severe levels of infestation and damage. Sufficient early season rainfall favoured good establishment and growth of early season maize and sorghum crops on which the early large *H. armigera* populations were able to build up before they dispersed to cotton. In contrast, dry weather in particular mid-season droughts between January and March, caused notable declines in pest populations and resulted in low infestation and low damage on cotton, a situation reported in earlier work at Ukiriguru (Percy, 1974). Therefore, the weather conditions in January-February each season will greatly influence infestation and damage on cotton in February. Excessive heavy and windy rains in March-April may be unfavourable for the build up of the pest population as both eggs and small larvae are easily dislodged from the plants.

8.2 Relationships between H. armigera populations and host plant sequence

8.2.1. Significance of alternative hosts

8.2.1.1 - Direct host plant effects - Plant host-insect interactions occur at many different levels and in H. armigera are greatly complicated by a large crop host range of different susceptibilities and agronomic characteristics with considerable spread of sowing dates as well as by wild hosts, thus providing both spatial and temporal diversity, which is typical of the study area. H. armigera pressure on cotton will thus depend very largely on the influence of other host plants grown prior to and in conjunction with the cotton crop (Parsons, 1939).

This study has shown that the attractive stages of its main alternative hosts overlap to provide continuous pest populations throughout the year. Earlier work to investigate the role of cultivated alternative H. armigera host plants in WCGA, Reed (1965b) identified maize as the main host on which the pest population built before migrating to cotton in February. Reed (1967) also noted that, although sorghum was a favoured host of the pest very few larvae survived to pupation because the varieties grown at that time had open panicles which afforded little protection from parasites and predators. In contrast, many larvae survive to adults on maize because the larvae feed well hidden in the cobs where they are protected from their natural enemies. These observations suggest that early sowing of maize might be banned in order to interrupt the generation of the pest prior to that which attacks cotton, thus

reducing the pest population pressure on early sown cotton. However, maize has gained popularity as a staple food in many areas of WCGA and, since farmers depend on the food they grow as well as cotton, they give priority to food crops. Thus, prohibiting the sowing of early maize is impractical as late sown maize would be adversely affected by dry weather. Secondly, in recent years, the open panicle sorghum cultivars have been replaced by close panicle (eg. Serena variety) and semi-dense panicle (eg. Lulu variety) varieties on which H. armigera larvae are more likely to survive to adults as these provide more protection to the bollworm larvae from predators and parasites than do the traditional open panicle types (Doggett, 1964; Wilson, 1976). Therefore, despite the fact that the level of parasitism and possibly predation may be higher on sorghum than on maize, sorghum was often more heavily infested and therefore many larvae survive to adults. Cotton grown adjacent to sorghum fields was often found to suffer a rapid build up of H. armigera as the sorghum crop reached maturity (Peat, 1957). Thus, maize and sorghum are equally important sources of the pest population which attack cotton early in the season.

Between February and April, the critical period for the cotton crop, the H. armigera population pressure on cotton was very much influenced by the abundance of available suitable sorghum and maize in flower. Whenever mid season drought occurred both maize and sorghum were more adversely affected than cotton and the pest population pressure on cotton was relatively high. However, in non drought situations where all three crops were commonly available at

the same time in suitable stages, cotton was still infested but the level of infestation was lower and was also lower than that on either maize or sorghum (Peat, 1943, Peat, et al, 1954; Peat, 1956). The availability of these alternative hosts did not therefore mean complete diversion of the pest population from cotton. However, the potential pest pressure was reduced as the pest population distributes over a wider area, with higher levels of infestation on the most preferred host plants. Thus, although early sown maize and sorghum are a potential threat to the cotton crop, later sown crops notably the long maturing maize which flowers in April-May are advantageous to the cotton crop. These findings contrasts with the situation in Uganda where the pest population from one host seemingly had no influence on the other alternative hosts even when their flowering cycles overlapped (Coaker, 1959).

Maize in WCGA does not suffer economic yield losses from attack by H. armigera and therefore as regards the maize crop, the present farming system does not justify change. The long maturing maize sown in January-February can suffer heavy yield losses from maize streak virus which is very common in WCGA. The current research efforts to breed and select for maize streak resistant varieties should be emphasized.

In contrast, H. armigera attack on sorghum can lead to heavy grain yield losses if uncontrolled. Therefore, effective control measures on sorghum which should aim to kill the small larvae before they cause heavy damage to the grains will not only ensure a good

harvest but will also reduce the size of the likely potential adult pest population which can disperse to cotton.

Reed (1965a) reported that late sown maize was a source of diapause pupae. However, throughout the study only one diapause pupa was recorded on maize. The recent introduction of tomatoes in the area and the expansion of the acreage under chickpea has enabled the pest population to survive an otherwise adverse weather condition. The late season generations from maize, sorghum and cotton disperse to Cleome and/or tomatoes and chickpea where they survive the dry weather.

Cleome sp. is an important host plant for the pest population early in the season before both maize and sorghum begin flowering. Thus, Cleome forms a bridge between the dry and wet season host plants whereas tomatoes bridges chickpea and Cleome at the beginning of the short rains in October.

8.2.1.2. Influence on natural enemy activity - Evidence from the study shows that the levels of H. armigera larval parasitism and diseases (viral and bacterial) on its alternative hosts were seasonal and were related to host plant factors, the feeding behaviour of the larvae on its different hosts and aspects of weather. Many of the parasitoids recorded are not host specific and have been recorded attacking other lepidopterous pests (Table 18). Therefore they may not be well suited for the control of H. armigera. However, a few were host-plant specific. It should therefore be possible to enhance

the activity of the key parasitoids on their preferred host plants and so reduce the size of the potential pest population on that host. Thus, in WCGA, the augmentation of A. diparopsidis which kills small larvae, and P. laxa, which attacks large larvae, on the early sown sorghum crop could help to ensure a good grain yield and less larvae surviving to adults. This may have an added advantage because P. laxa is a common parasitoid on cotton and chickpea (Table 42) and could build up to large numbers early in the season. This would be particularly useful in a year when parasites are naturally scarce. The study also provided evidence that the abundance of the parasitoids is of a seasonal nature (Table 43) (Robertson, 1973).

The records of H. armigera larval parasitoids species at Ukiriguru from the early 1960's to date (Table 43) shows that there is still much to be learnt about the parasites. The differences of species recorded is probably partly due to differences in the range of alternative host plants included in the study, although seasonal differences cannot be wholly ruled out. However, of interest is the fact that the tachinids recorded in 1961 (Robertson, 1973) were also recorded in the present study, with P. laxa featuring in both cases as important. P. laxa was also considered by Reed (1965b) to be important. Charops sp. was recorded as an important parasitoid on legumes (Reed, 1965b) and in this study it was common on chickpea, a legume. Netelia sp. was recorded (Reed, 1965b) as an important parasitoid of H. armigera between 1962-64 but was only occasionally recorded in the current study, this showing an overall change in abundance of certain species over the years, a trend which is worth further investigation.

Table 42. H. armigera larval parasitoids and pathogens that were most common on different host plants in 1980-85.

Host plant	Parasitoid	Pathogens
<u>Cleome</u>	<u>Charops</u> sp, <u>Cardiochiles</u> spp	NPV, Bacteria
Tomato	" "	Bacteria
Maize	<u>Apanteles</u> <u>diparopsidis</u>	NPV, Bacteria
Sorghum	" " , <u>Palexorista</u> <u>laxa</u>	Bacteria
Cotton	<u>Cardiochiles</u> spp, <u>P. laxa</u>	Bacteria
Chickpea	<u>Charops</u> sp, <u>Paradrino</u> <u>halli</u> , <u>P. laxa</u>	Bacteria

Cleome and tomatoes were potential reservoirs of parasitoids throughout the season notably for Charops sp. and Cardiochiles spp. attacking H. armigera on cotton and chickpea (Table 42). Therefore, it seems important to maintain the Cleome sp. as a parasite source in the agro-ecological zone. A current move to use herbicides in maize and cotton fields should be viewed with caution as this could make the weed much rarer. Chickpea enables the pest and its natural enemies to survive the dry season and thus eliminates the 'lag behind' phenomenon reported by Reed (1965b) between the pest and its enemies early in the season.

Insect pathogens, notably baculoviruses, are host specific and can cause rapid insect population declines (Tinsley, 1979). As for parasitoids, disease susceptibility by larvae can be influenced by the food plant (Vago and Cayrol, 1955). Vago and Cayrol (1955) found that, the kill of Plusia gamma caterpillars by the virus Borrelina was 60-100% on cabbage, less than 60% on Plantago sp. and only 20% on Sonchus sp. Therefore, the differential susceptibility to pathogens of H. armigera larvae on its alternative hosts (Table 42) might be exploited by enhancing the pathogen on those host plants where it is likely to be most effective. In WCGA, bacterial diseases could be used on several alternative hosts (Table 42) but they are less suitable than viruses because larval mortality does not occur until the late instar. NPV on the other hand kills small larvae before they can cause heavy damage to the crop. Local NPV strains have been shown to be far more effective in controlling H. armigera larvae than exortic commercial strains (Roome, 1975; Cadou and Soubriér, 1974)

and therefore more research is needed to develop good formulations and application techniques and assess local strains (Nyambo, 1984). In WCGA, NPV could be augmented on the early sown maize crop although an attempt to use the pathogen on sorghum could also be rewarding. Roome (1975) experimented with local strains of NPV on sorghum in Botswana and achieved good control of H. armigera larvae.

8.3 Techniques for monitoring and forecasting H. armigera on cotton

Cotton spraying in WCGA begins at first flower and continues throughout the flowering period of the plant. However, the occurrence of H. armigera infestations may vary in space and time. The timing and level of infestations are likely to vary in different seasons or on adjoining crops of different ages in the same season, this making the rational timing of control measures dependent on crop scouting to ascertain the actual level of infestation on the target crop (Gledhill, 1981). Therefore, the economic control of H. armigera on target crops will depend on success in predicting the likely level of infestation and defining the economic damage threshold and the proper timing of appropriate control measures (Way and Cammell, 1977).

Monitoring of a pest in order to give advance warning (forecasting) can be done at source on pre-crop host (alternative host) and/or using interception traps (Way, Cammell, Taylor and Woiwod, 1981). Whichever method is used, the cost and convenience of operation and warning procedures are important constraints. Both methods were evaluated during the study and the merits and limitations of their use in WCGA will be discussed.

8.3.1. Forecasting from alternative host source

In WCGA, maize is the only host crop on which H. armigera does not cause economic damage (a tolerant crop) and it was considered an ideal host for monitoring purposes. An attempt was made to monitor the abundance of the 5th and 6th instar larvae and relate their pupation period and adult emergence to the stage when the cotton plant is susceptible. Although it was possible to establish a relationship between H. armigera adult emergence, level of infestation on cotton and cotton plant phenology, it was concluded that the greatest benefit of such a forecast would be to predict the timing of the first infestation on the early sown cotton. This requires monitoring the maize crop at the dough stage in January and relevant knowledge of the biology of the pest. The greatest benefit from this would be to give several weeks of advance warning to the extension service department to organize individual field scouting and spraying.

Source monitoring has several limitations in WCGA. First, skilled labour is needed to monitor the larvae and make accurate forecasts. This is not readily available and therefore necessitates the need to invest heavily in training and supervision of operators. It will also require trained operators and farmers to recognize the early stages of the pest and this will need much investment of money, time and expertise. Secondly, a heavy infestation on maize in January may not necessarily result in a large adult population as this is very much influenced by the weather conditions in January-February. This makes it necessary to have access to good

local rainfall records which may not be available over much of WCGA. Thirdly, temporal diversity, mainly due to sequential maize sowing in WCGA does not offer consistent plant phenology needed to make accurate and reliable sampling and forecasts. This is in contrast to the situation in South Africa (Morton, 1979) where the first infestations on cotton could be reliably predicted from maize at the tasselling stage.

8.3.2. Monitoring with pheromone traps

Pheromone traps were used to monitor the activity of the adult males in flight and the catch was translated to an infestation and/or damage threshold on the target crop. If a catch threshold is reached, then this is used as a warning to scout the target crop for an infestation. The traps are selective and catch only sexually mature males and therefore do not require skilled labour to operate, an advantage over source monitoring. Pheromone trapping is time saving and because they are low cost operating, traps can be used over large areas at the same time and the information so obtained used to issue local forecasts or warnings to farmers to inspect individual crops for an infestation. This may require farmer training to recognize the pest at early instars, as for source monitoring, but the technique is advantageous in that it involves only one level of training and supervision. A major benefit would be to enable farmers to recognize instars of the pest early before the small larvae cause heavy damage to the crop.

The reliability of pheromone trap forecasting will depend on

accurate interpretation of the catch in relation to the prevailing weather conditions and crop phenology. The main limitation is that, whereas it may be possible to make accurate early season warnings, as the season advances later catches may be difficult to interpret because of increased competition between the trap and the wild female population. Secondly, pheromone trapping can be used to give only about a week's advance warning and therefore does not allow plenty of time to organize and supervise individual field scouting and spraying. However, the greatest benefit would be to be able to time the first spray on cotton accurately which would save chemical and extend the activity of natural enemies.

8.4 Practical approaches of monitoring and forecasting H. armigera

Most cotton farmers recognize the damage caused to cotton by H. armigera and can also identify the well grown larvae. A few of the farmers use the abundance of damaged buds and/or the well grown larvae to decide when to spray. The small larvae (1st and 2nd instar) of H. armigera cause little damage to the crop and therefore in any control plan the strategy should be to control the pest during the early instars. This would be possible by weekly scouting for fresh damaged buds or flared squares as these will give a direct indication of the presence of the pest. Thus, there was a need to establish an economic damage threshold that can be used as a guideline by the innovative farmers at the individual field level.

Basic requirements for implementation of such a guideline are:-

- 1) training programmes for the field assistants to enable them to

recognize the need for and importance of a forecasting system and to recognize the pest and be able to relate weather and likely levels of infestation and to issue warnings to farmers.

- 2) training of field assistants to keep accurate daily records and rainfall data, and also be able to interpret the catch. A simple 'yes' or 'no' weekly record system could be used. The daily records from individual sites will be useful in future improvement of the monitoring and forecasting programme.
- 3) training of field assistants and farmers to scout individual fields, to recognize pest damage at an early stage and to appreciate the need to apply control measures when the damage threshold is reached.
- 4) to establish contact with innovative farmers who will receive the initial training and be used to train others.
- 5) that farmers should inspect their individual cotton fields once a week beginning when the first flowers appear preferably on the same day each week until the first bolls split. Depending on the distribution, duration and amount of the heavy rains in March-May, a farmer may have to continue scouting his crop beyond first boll split if there is a good potential for a top crop.
- 6) training farmers to record individual field operations. These could be used to improve the farmers package for area wide advice. Also, this will ensure continuity and practical feedback.

8.4.1 Damage thresholds and spray timing

The results of the trials to investigate infestation and damage

thresholds were inconsistent between sites and seasons. The calendar spraying regime gave an overall higher yield of seed cotton and higher economic returns to spraying largely because the thresholds used were either too high or too low. Despite the above results, the immediate need is to minimize yield losses caused by H. armigera, in particular where farmers already use 'scouting' to decide when to spray. After all, the majority of the farmers do not adhere to the routine spraying regime. Thus, although the damage thresholds assessed were not as good as the calendar spraying regime, the 0.5 flared squares per plant threshold level gave an overall better H. armigera damage control and higher economic returns than any of the other thresholds used. Allowing for flexibility of the damage level, the 0.5 flared squares per plant per count or 0.5 total flared squares in two consecutive counts was even more profitable. This damage threshold is recommended for use by those farmers who already 'scout' their crop pending future research work. It must be stressed that this is only a provisional economic threshold which can be modified and improved with experience.

It has been shown in the study that often there is very little time lag between evidence of infestation and the crop being damaged. This means that, to prevent further damage to the crop, chemical treatment must be applied in the same week as the threshold is reached, preferably the day after. Failure to implement this could lead to economic yield losses.

8.4.2. Pheromone traps, damage thresholds and spray timing

The relationship between moth catch in the pheromone traps and the level of infestation and damage to cotton was investigated over several sites in WCGA. Although the levels and timing of infestations and damage varied between sites and seasons, the results showed that there was about one week time lag between moths caught and subsequent crop infestation and damage. It was also shown that the catch threshold was 10 moths per week. However, occasionally no relationship could be established between the weekly moth catch and the level of infestation even when the catch was well above the threshold. It is possible that under such circumstances, either natural enemies were rapidly depleting the H. armigera eggs and small larvae and/or the phenology of the plants was unattractive to ovipositing adult females and/or there were other more attractive alternative host plants for H. armigera in the vicinity.

The study showed that the level of H. armigera natural enemies on cotton before the spraying programme commenced was often relatively high but declined rapidly as soon as routine spraying started, as reported in South Africa (van Hamburg, 1980). Thus, it is envisaged that trapping is especially useful in timing the first spray application which may lead to a delay in starting the first routine spray and so prolong the activity of the natural enemies.

Pheromone trapping can begin early in the season but forecasting and scouting will be most economic if started when the first flowers begin to appear on the cotton plants. Therefore, the moth catch

threshold should be used as a precursor for monitoring infestation and damage in the cotton crop.

8.4.3. Potential advantages and disadvantages of the use of damage thresholds for timing insecticide applications

In many countries, eg. Malawi, egg thresholds are used to determine spray timing (Matthews and Tunstall, 1968). However, for the WCGA in Tanzania damage thresholds have been chosen instead of such thresholds for the following reasons:-

- a) damage thresholds allows biological control of eggs and small larvae by delaying a chemical treatment, especially early in the season. In WCGA, there is often a high early season build up of parasites and predators (coccinellids, syrphids and chrysopids) in cotton before spraying begins. However, the population of natural enemies declines rapidly soon after routine spraying commences.
- b) damage thresholds are easy to implement, in particular by individual farmers who may not have the skill and time to search for eggs and small larvae.
- c) damage thresholds may lead to less chemical treatments and hence reduce environmental contamination.

However, damage thresholds have the following limitations:-

- a) if the damage threshold which is used is too low, sampling costs will increase because a larger plant sample will have to be examined to maintain accuracy and this will inevitably lead to an increase in the sampling error. Consequently, a situation may arise where a necessary treatment is erroneously omitted or

unnecessary treatment is applied. In both cases, economic losses may occur.

- b) If the level of infestation is persistently low over a prolonged period rather than occurring in an identifiable peak, the level of damage may remain persistently below the chosen damage threshold and this will lead to economic losses, a case which was reported over several sites in the study.
- c) with damage thresholds damage has already been done, so there is a premium on very quick implementation of pesticide application compared with an 'egg' threshold.

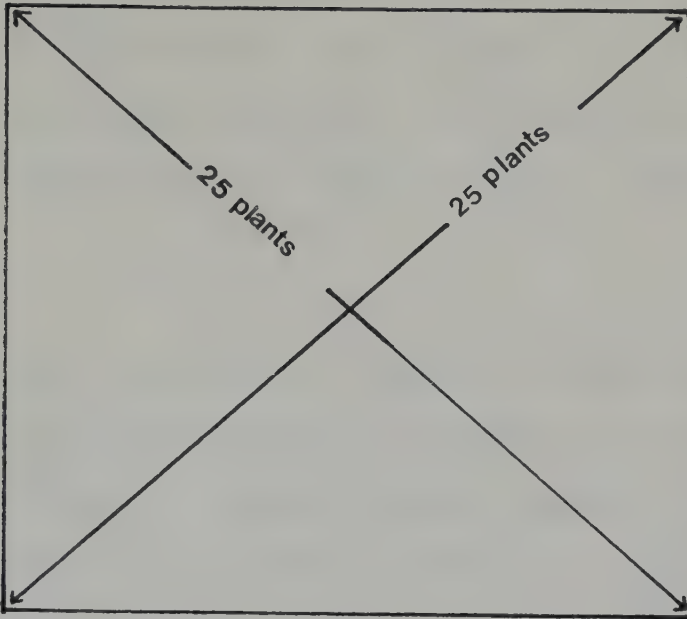
8.4.4. Suggestions for implementation of threshold spraying

These are as follows:

- a) start scouting at first flower and continue weekly on the same day until boll split. If there is a pheromone trap in the area, begin the first scouting when moth catch reach 10 moths or more in a week.
- b) if the damage threshold is reached, spraying must be done in the same week, preferably a day after the scouting.
- c) if the field is more than an acre in size, divide it into one acre-blocks. Examine 50 plants per block of one-acre on the diagonals of the field such that 25 plants are examined along each diagonal (Fig. 65). Count only the freshly H. armigera damaged buds or flowers. Use a peg board guide.

(A simple peg-board for recording the numbers of plants, numbers of flared squares and the threshold levels)

Fig. 65. Diagrammatic illustration of how to conduct scouting for H. armigera damage level in a cotton field.



- e) spray only when the level of damage reaches 0.5 flared squares or flowers per plant per count or 0.5 total flared squares or flowers in two consecutive counts.
- f) use the recommended insecticide for your area at the correct dosage rate.

GENERAL SIGNIFICANCE OF RESULTS AND FUTURE NEEDS

A survey of the incidence of H. armigera on different host plants (maize, sorghum, cotton, chickpea, tomato and Cleome sp) in the western cotton growing area of Tanzania was done between 1980-81 and 1984-85 seasons. The survey was conducted in the small scale farming systems typical of Western Tanzania. The results were as follows:

1. The level and timing of infestation within and between seasons was influenced by the amount and distribution of rainfall.
2. The flowering (attractive stages) patterns of the different alternative host plants overlap to give continuous pest population generations throughout the year, with peak populations occurring during the rainy period when most of the host plants were abundant.
3. Maize and sorghum were found to be important hosts on which a large population of H. armigera built up early in the season before attacking cotton in February. However, the size of the effective adult population originating on these hosts was very much influenced by the amount and distribution of rainfall in January and February.
4. The pest population on cotton begin to build up in mid January reaching a peak in March. The pest population in March was the most damaging as the cotton was at peak flowering. The level of infestation and damage in any season on cotton was influenced by the availability and abundance of suitable maize and sorghum in

flower, as these two crops are relatively more attractive to ovipositing H. armigera. The current farming system which allows sequential sowing of maize from October to February and late season and ratoon sorghum should not be discouraged.

5. The late season generations on maize, sorghum, cotton and Cleome disperse to tomatoes and chickpea. Often, the late generations on Cleome overlapped the first generation on chickpea.
6. Cleome was an important wild host plant on which the pest population built up early in the season before maize and sorghum begin flowering, and it remained an important secondary host of the pest throughout the season. This weed forms a bridge between the dry season and the rainy season crops. Cleome was also found to be a good reservoir for a wide range of H. armigera natural enemies throughout the year. It was identified as a good source of pollen and nectar to adult parasites and predators especially early in the season before the crops begin to flower. It was also speculated that Cleome may be a good reservoir of the pest population which may provide a good diluent of pesticide susceptible strains of H. armigera should insecticide resistant strains develop on cotton because of increased use of insecticide spraying.

Despite the fact that Cleome sp. flower throughout the year, it was not a suitable host for H. armigera during the dry season, July - September. Plant factors, possibly physical and/or chemical could render it unsuitable for H. armigera oviposition and development. Such factors might be exploited for the management of H. armigera in crop situations if fully researched.

7. Tomato and chickpea were important host plants of the pest during the dry season. Tomato formed a bridge between dry season crops and Cleome.
8. Pupal diapause was found to be less than 0.5% throughout the study period, which was very much less than was reported in the mid 1960's. The recent introduction of commercial tomato production and the expansion of the area under chickpea both of which are cultivated during the dry season has enabled the pest population to survive otherwise unfavourable conditions. However, there was some doubt as to the identity of the diapausing species and this needs further investigation.
9. H. armigera larval mortality factors were assessed on its different alternative host plants. Field collected larvae were reared individually up to adult stage in the insectary on food plant on which they were originally collected. The larvae were observed daily for diseases and parasites until they either died or pupated. Diseases (viral and bacterial) and parasitism were found to be important. Overall, the level and timing of larval diseases and parasitism varied between seasons and was found to be related to host plant factors, the feeding behaviour of H. armigera larvae on its different host plants and weather aspects. Thus, although there may be a high build up of larval diseases and parasites early in the season on Cleome, maize and sorghum, the level of parasitism and diseases on the pest population on cotton may not necessarily be high. The differential attractiveness of different crops or cultivars to parasites as opposed to the pests themselves and the

differential susceptibility of H. armigera larvae feeding on different alternative hosts to pathogens need further research for successful augmentation of these natural enemies. The biology and ecology of the most commonly recorded parasites needs investigation before their full potential can be exploited. With regard to pathogens, NPV appear to be the most promising agent but intensive research in formulations and application techniques notably with local strains is required.

10. Larval diseases and parasitism on cotton were notably scarce and tended to decline further when routine spraying began. As mortality factors they could not prevent the pest from causing economic damage to the crop.
11. Other mortality factors including larval predation, cannibalism and adverse weather conditions were not intensively studied. However, larval cannibalism may be important on maize but insignificant on sorghum, whereas predation was an important mortality factor on the latter host. Dry weather conditions had both direct and indirect adverse effects on the build up of the pest population on the alternative host plants. Often, mid-season droughts caused drastic population declines.
12. The prospects for forecasting the pest occurrence on cotton were assessed. H. armigera 5th and 6th instars were monitored on maize, the only tolerant crop in WCGA, in order to predict the first infestations on cotton. It was concluded that in order to provide a practical forecast it is necessary to take into consideration the timing, amount and distribution of the short rains as well as the rains in December and January as these

would influence the timing and level of infestation on the early sown maize. The general weather trends in January and February have also to be considered as they will influence survival of the pest population on maize and the overall condition of cotton plants. Temporal diversity due to sequential maize sowing in WCGA does not offer consistent plant phenology needed to make accurate and reliable sampling and forecasts.

13. Monitoring and forecasting H. armigera using light and pheromone traps and crop inspection was investigated. The initial work involved the assessment of simple pheromone trap designs to identify a suitable trap for use in Tanzania. Trap designs and colours were studied and the Ukiriguru trap design was found to be suitable and was used over several sites in Tanzania to study the activity of H. armigera. However, there is a further need to investigate appropriate trap construction and colour.

Trap placement height in cotton and chickpea crops were studied. In cotton, the trap should be maintained above the canopy, preferably not above 80 cm whereas in chickpea, 25 cm above the crop canopy was found to be the optimum height beyond which catch declined significantly.

The efficiency of the pheromone trap catches relative to the light trap was studied using moth catches in 1982, 1984 and 1985. Overall, the pheromone trap catch followed a similar trend to the light trap in monitoring the general activity of the moth population. The pheromone trap was more sensitive at low pest populations. However, the light trap caught a proportionately larger H. armigera moth population than the

pheromone trap notably at peak populations. Moth catch at the pheromone trap increased relatively as the number of females caught in the light trap decreased.

Overall, there was a significant positive correlation between numbers of males and females caught in the light trap. The relationship between the number of males caught in the pheromone trap and the number of females and males caught in the light trap was unclear; in two out of the three seasons no relationship could be established. Knowledge of the age structure of the moths caught in the light trap is needed in order to establish a better understanding of the trap data.

Adult emergence in the insectary together with light and pheromone trap data were used to study the seasonal variation of H. armigera populations in WCGA. It was established that H. armigera in WCGA was active throughout the year with low activity during the dry season. The pattern of population changes was similar over many areas in WCGA but the abundance of the pest population varied in time and space. The level of pupae diapause in the population is very low and therefore the pest may be surviving on a range of alternative hosts including wild plants which were not included in the study. Therefore, more research is needed to identify and assess the role of such hosts in the dynamics of H. armigera. The role of tomatoes was only partially studied and it would be interesting to investigate this host throughout the season.

The use of light and pheromone traps to monitor and forecast the level of infestation and damage in cotton was assessed.

Overall, the pheromone trap was found to be more sensitive compared to the light trap in estimating the proportion of the ovipositing female population. Despite site to site and seasonal variations in the level of H. armigera infestation, there was an overall positive relationship between the number of moths caught in the pheromone trap and the level of infestation over several sites. Often, there was one week lag between the timing of peak moth catch and the build up of the infestation. The catch threshold was found to be 10 moths per week. It was also established that there is no time lag between the level of infestation and damage to cotton and therefore chemical treatment should be applied within the same week once a certain level of infestation and/or damage is reached to prevent further damage and crop loss. Therefore, the moth threshold should be a precursor to monitor the cotton crop for infestation and spraying should be done only when the spraying threshold is reached.

14. Spraying of cotton in WCGA for control of H. armigera is based on a routine schedule which does not take into account differences in pest population levels in time and space. Scouting trials were carried out to find a suitable H. armigera damage threshold on which to base spraying to improve the timing of spray application and to identify areas of high attack which may need more sprays or alternatively, areas of low attack where insecticides can be saved. The results of the thresholds assessed were variable and inconsistent between sites and seasons, with the routine schedule giving higher yields of seed

cotton and more economic returns. In retrospect, the thresholds used were either too low or too high to give favourable economic returns to spraying. Thus, more research is needed before the full potential of threshold spraying in WCGA can be assessed. However, since most farmers in WCGA do not follow the current routine spraying recommendation, the immediate need is to minimize yield losses particularly to the innovative farmers who already 'scout' their cotton for damage before spraying. Thus, a provisional spraying damage threshold has been suggested pending future research.

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Appendices

Appendix I

HELIOTHIS ARMIGERA SURVEY ON CULTIVATED CROPS

Recorder Date:

SITE

CROP

SOWING DATE

Fertilizer Applied

At sowing

Top Dressing.....

Cropping System

Monoculture

Mixed - if mixed name crops:

Insecticide Application

	Name of chemical	Rate of Application	Date of Application
1.
2.

Plant No.	Plant growth condition	AMERICAN BOLLWORMS					
		Eggs			Larvae		
		Number found	Where found	Predator	Number found	Where found	Predator
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

NB Collect eggs and larvae for rearing in the insectary

Appendix 2

Seasonal incidence of larval parasitism and diseases of H. armigera at Ukiriguru on all host plants - records from larvae collected in the field, 1981-82 season.

Month	Total number of larvae observed	% Diseased larvae	% Parasitized larvae	% other mortalities
Oct	267	42.7	6.7	7.5
Nov	122	27.0	13.1	2.5
Dec	404	5.2	17.6	2.5
Jan	729	14.9	50.6	5.8
Feb	680	12.3	17.6	3.9
Mar	587	18.6	10.1	0.0
Apr	961	28.1	1.2	1.0
May	678	18.7	9.7	0.0
June	948	17.4	8.5	11.1
July	1342	6.8	2.9	39.5
Aug	1377	6.9	2.6	34.4
Sept	163	10.0	1.8	0.0

1982-83 season.

Oct	166	8.4	11.4	4.8
Nov	538	10.6	32.3	1.1
Dec	656	31.4	14.9	1.0
Jan	2008	41.4	7.8	1.4
Feb	1291	38.2	8.2	0.0
Mar	938	27.6	6.3	0.0
Apr	659	26.7	7.0	1.8
May	695	20.8	11.8	2.6
June	880	11.7	14.3	8.6
July	1912	8.1	4.6	3.0
Aug	1075	10.9	2.0	1.0
Sept	464	10.3	0.0	0.0

1983-84 season.

Oct	324	3.7	20.4	16.6
Nov	778	3.9	15.2	7.9
Dec	1335	25.6	18.5	5.2
Jan	590	34.6	11.7	6.1
Feb	232	34.0	1.7	6.4
Mar	981	10.3	5.4	6.8
Apr	1066	21.9	6.5	5.1
May	752	25.8	8.5	3.2
June	444	11.9	1.6	7.4
July	356	19.4	3.1	4.8
Aug	580	21.9	5.2	7.2
Sept	20	15.0	10.0	25.0

Appendix 2 (Continued)

1984-85 season.

Month	Total number of larvae observed	% Diseased larvae	% Parasitized larvae	% other mortalities
Oct	230	2.6	31.7	1.7
Nov	615	13.9	38.4	4.5
Dec	542	24.7	31.9	3.1
Jan	1958	34.7	6.4	2.4
Feb	431	59.4	10.7	4.1
Mar	226	36.7	10.2	0.9
Apr	286	32.1	14.3	2.1
May	533	31.3	10.3	3.4
June	640	29.0	9.5	2.6
July	782	13.2	9.9	3.0
Aug	761	20.1	4.5	8.1

Appendix 3

Summary of H. armigera larval density per plant on its alternative
host plants 1981-82 to 1984-85

1. Cleome sp.

Calendar Week	Seasons				mean
	81-82	82-83	83-84	84-85	
40	.13	.12	.22	.01	.12
41	.25	.08	.26	.00	.15
42	.27	.12	.52	.26	.29
43	-	.30	.30	.29	.29
44	-	.46	.52	.50	.49
45	.17	.37	.57	.18	.32
46	.25	.35	.40	.27	.32
47	.42	.17	.36	.37	.33
48	-	.26	.25	.64	.37
49	.51	.42	.60	.25	.44
50	.44	.32	1.01	.23	.50
51	-	.23	.36	.26	.28
52	-	.52	.56	.43	.50
1	.67	.58	.46	.22	.48
2	.62	.66	.24	.48	.50
3	-	.50	.17	.52	.39
4	.50	.52	.38	.42	.45
5	.60	.32	.06	.32	.32
6	.60	.42	.08	.27	.33
7	.30	.56	.02	.23	.28
8	.52	.75	.13	.30	.42
9	.00	.74	.17	.07	.24
10	-	.64	.22	.21	.35
11	.30	.73	.12	.11	.31
12	.56	.66	.31	.08	.40
13	.77	.72	.42	.17	.52
14	1.00	.48	.64	.26	.59
15	1.05	.60	.50	.28	.61
16	.86	.56	.63	.32	.59
17	.93	.55	.88	.34	.67
18	.40	.48	.50	.43	.45
19	.47	1.16	.82	.30	.68
20	.57	.94	.41	.22	.53
21	.36	.36	.27	.30	.32
22	.18	.31	.05	.62	.29
23	.26	.53	.02	.48	.32
24	.20	.40	.00	.24	.21

? compare 1981-82

, 46

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Appendix 3 (Continued)

Cleome sp. continued

Calendar Week	Seasons				mean
	81-82	82-83	83-84	84-85	
25	.20	.13	.00	.46	.19
26	.13	.23	.00	.05	.10
27	.10	.10	.00	.06	.06
28	.00	.00	.00	.03	.007
29	.00	.00	.00	.00	.00
30	.00	.00	.00	.00	.00
31	.00	.04	.00	.00	.01
32	.00	.00	.00	.00	.00
33	.00	.03	.00	.00	.01
34	.00	.00	.02	.00	.01
35	.00	.00	.004		.001
36	.00	.00	.01		.00
37	.00	.00	.004		.001
38	.00	.00	.00		.00
39	.00	.00	.00		.00

2. Maize

Calendar Week	Seasons				mean
	81-82	82-83	83-84	84-85	
48		.00			.00
49	.10	.00		.00	.03
50	.28	.56	.60	.00	.22
51	.20	.70	.68	.23	.42
52	.52	.76	.30	.40	.48
1	.68	.70	.33	.37	.53
2	.38	1.03	.26	.48	.45
3	.35	.64	.18	.46	.50
4	.89	.40	.20	.38	.53
5	.35	.98	.18	.33	.31
6	.67	.52	.08	.16	.47
7	1.00	.74	.05	.30	.46
8	.80	.50	.13	.04	.42
9	.70	.26	.12	.04	.34
10	.43	.24	.06	.00	.18
11	.80	.18	.07	.12	.31
12	.63	.26	.03	.00	.21
13	.88	.26	.32	.06	.38
14	.72	.26	.24	.00	.30
15	1.32	.34	.24	.06	.49
16	1.25	.55	.40	.00	.55
17	1.10	.23	.90	.11	.58
18	1.13	.40	.37	.18	.52
19	.40	.52	.38	.15	.36
20	.30	.22	.10	.06	.17

Appendix 3 (Continued)

2. Maize continued

Calendar Week	Seasons				mean
	81-82	82-83	83-84	84-85	
21	.40	.10	.15	.07	.18
22	.40	.06	.00	.00	.11
23	.10	.00			.05
24	.10	.00			.05

1.10

3. Sorghum

Calendar Week	Seasons				mean
	81-82	82-83	83-84	84-85	
49	.00				.00
50	.02				.02
51	3.65				3.65
52	.00	.80		1.70	.85
1	.50	2.84	.65	.27	1.06
2	.49	1.45	.00	.45	.59
3	.54	2.77	.01	.65	.99
4	.44	.27	.04	.62	.34
5	.64	.27	.00	.64	.38
6	1.22	.65	.01	.43	.57
7	.83	.46	.07	.35	.43
8	.54	.40	.00	.18	.28
9	.46	.20	.05	.00	.18
10	.52	.26	.00	.00	.19
11	.60	.25	.00	.00	.21
12	.95	.38	.00	.03	.34
13	.10	.15	.00	.00	.06
14	.20	.02	.10		.08
15	.20	.12	.02		.08
16	.80	.28	.10		.29
17	.00	.23	.28		.12
18	.10	.30	.16		.18
19	.20	.16	.10		.15
20	.60	.31	.15		.35
21	.20	.00	.00		.06
22	.10				.10

.75

.42

.23

.13

.20

.08

Appendix 3 (Continued)

4. Cotton

Calendar Week	Seasons				mean	
	81-82	82-83	83-84	84-85		
3	.30	.70		.30	.43	0.58
4	.15	.85		.00	.33	
5	.05	.85	.03	.26	.29	
6	.05	1.20	.05	.26	.39	.32
7	.17	.60	.03	.25	.26	
8	.23	.66	.17	.30	.34	
9	.13	.54	.06	.10	.21	.29
10	.63	.65	.06	.05	.35	
11	.27	.52	.37	.13	.30	
12	.40	.31	.37	.06	.30	.225
13	.06	.42	.34	.15	.24	
14	.00	.16	.51	.13	.20	
15	.06	.30	.45	.25	.26	.18
16	.08	.22	.38	.14	.20	
17	.38	.06	.35	.17	.24	
18	.25	.25	.26	.12	.22	.097
19	.30	.08	.13	.02	.13	
20	.22	.02	.16	.20	.15	
21	.20	.01	.07	.23	.13	
22	.15	.02	.00	.20	.09	
23		.01	.00	.20	.07	

5. Chickpea

Calendar Week	Seasons				mean
	81-82	82-83	83-84	84-85	
18			1.1		
19			.96		
20			.70		
21			.47		
22		.16	.31		
23	.00	.30	.32		
24	.44	.16	.36	.00	.24
25	.34	.24	.26	.24	.27
26	.78	.42	.41	.75	.59
27	.56	.64	.68	.86	.68
28	.50	.93	.50	.40	.58
29	.45	.97	.50	.37	.57
30	.43	.26	.25	.52	.36
31	.42	.28	.23	.35	.32
32	.34	.37	.00	.48	.29
33	.57	.52	.00	.37	.36
34	.65	.51	.00	.60	.58
35	.45	.41		.52	.46
36		.22			
37		.03			
38		.80			
39		.25			

Appendix 3 (Continued)

6. Tomato

Calendar Week	Seasons				mean
	81-82	82-83	83-84	84-85	
40	.86	.34	.00	.03	.31
41	.36	.30	.10	.00	.50
42	.77	.16	.24	.00	.48
43	.70	.13	.12	.02	.53
44	.32	.05	.08	.00	.35
45	.14	.13	.28	.00	.25
46	.08	.15	.17	.00	.24
47		.16	.08	.00	.18
48		.15	.01	.00	.13
49		.07	.02	.00	.08
50		.00	.12	.00	.07
51		.00	.20	.00	.10
52		.02	.32	.20	.24
1			.26	.03	
2			.16	.00	
3				1.10	
4				.72	
5				.40	
6				.13	
7				.23	
8				.14	
9				.07	
23				.00	
24				.08	
25				.12	
26			.16	.14	.15
27	.05		.00	.05	.03
28	.00		.00	.00	.00
29	.05	.06	.01	.00	.03
30	.12	.04	.12	.02	.07
31	.00	.00	.12	.00	.03
32	.11	.04	.08	.00	.06
33	.05	.05	.03	.00	.03
34	.12	.02	.08	.00	.05
35	.15	.01	.08	.00	.06
36	.14	.02	.01		.05
37	.22	.05	.00		.09
38	.43	.02	.00		.15

Appendix 4. The total numbers of parasite adults emerging from H. armigera larvae collected in the field,

1981-82 to 1984-85 seasons.

1981-82 season

Parasites	Host Plants					
	<u>Cleome</u>	Tomato	Maize	Sorghum	Cotton	Chickpea
<u>Charops</u> sp	70	4	2	64	0	67
<u>Cardiochiles</u> spp	44	0	8	2	19	0
<u>Netelia</u> sp	2	0	0	0	0	0
<u>Apanteles diparopsidis</u>	4	0	17	202	4	0
<u>P. halli</u>	25	2	0	0	0	19
<u>P. laxa</u>	41	1	4	134	13	5
A	0	0	0	0	2	0

1982-83 season

Parasites	Host Plants					
	<u>Cleome</u>	Tomato	Maize	Sorghum	Cotton	Chickpea
<u>Charops</u> sp	54	6	1	0	3	152
<u>Cardiochiles</u> spp	233	8	4	0	96	3
<u>Netelia</u> sp	3	0	4	10	0	0
<u>C. (Microchelonus) curvimalatus</u>	4	0	13	116	11	1
<u>A. diparopsidis</u>	1	1	2	8	2	0
<u>Pristomerus</u> sp	5	0	0	0	0	0

Appendix 4. (Continued)

1982-83 season (continued)

Parasites	Host Plants					
	Cleome	Tomato	Maize	Sorghum	Cotton	Chickpea
<u>P. halli</u>	0	0	0	0	2	36
<u>P. laxa</u>	0	0	3	95	8	7
A	26	1	0	0	0	0
C	3	3	0	0	0	0
<u>Meteorus sp</u>	0	0	0	0	3	0

1983-84 season

Parasites	Host Plants					
	Cleome	Tomato	Maize	Sorghum	Cotton	Chickpea
<u>Charops sp</u>	120	26	1	1	4	36
<u>Cardiochiles spp</u>	292	15	5	1	12	0
<u>Netelia sp</u>	1	1	0	4	1	0
<u>C. (Microchelonus) curvamaculatus</u>	8	0	0	0	0	0
<u>A. diparopsidis</u>	25	0	18	2	10	0
<u>A. sp(vitripennis sp group)</u>	6	0	0	0	0	0

Appendix 4 (Continued)

1983-84 (continued)

Parasites	Host Plants					
	<u>Cleome</u>	Tomato	Maize	Sorghum	Cotton	Chickpea
<u>Pristomerus</u> sp	18	2	2	2	1	0
<u>P. halli</u>	0	1	0	1	0	18
<u>P. laxa</u>	1	0	0	26	4	3
A	14	4	0	0	0	0
C	4	0	2	0	0	0

1984-85 season

Parasites	Host Plants					
	<u>Cleome</u>	Tomato	Maize	Sorghum	Cotton	Chickpea
<u>Charops</u> sp	78	4	0	4	1	120
<u>Cardiochiles</u> spp	208	3	0	0	7	0
<u>Netelia</u> sp	6	1	3	3	2	0
<u>C. (Microchelonus)</u> <u>curvimaculatus</u>	1	0	5	4	3	0
<u>A. diparopsidis</u>	28	5	16	34	0	0
<u>A. sp. (vitripennis</u> sp group)	38	0	3	0	0	0

Appendix 4 (Continued)

1984-85 (continued)

Parasites	Host Plants					
	<u>Cleome</u>	Tomato	Maize	Sorghum	Cotton	Chickpea
<u>Meteorus</u> sp	1	0	0	0	0	0
<u>P. halli</u>	9	1	1	2	11	22
<u>P. laxa</u>	2	1	2	23	10	11
<u>Pristomerus</u> sp	32	0	1	0	1	0
A	25	0	0	0	0	0
C	7	0	0	0	0	0
E	9	0	0	0	0	0

Appendix 5. Summary of % parasitism and diseases on H. armigera larvae at Ukiriguru 1981-82 to 1984-85 seasonsa) Cleome sp.

Calendar		% Parasitism				% Diseases				
Week	81-82	82-83	83-84	84-85	Mean	81-82	82-83	83-84	84-85	Mean
40	0.0	0.0	5.8	0.0	1.4	0.0	0.0	11.7	0.0	2.9
41	6.2	0.0	19.7	0.0	6.5	0.0	0.0	6.2	0.0	1.5
42	25.0	0.0	27.4	22.2	18.6	0.0	4.1	0.0	1.2	1.3
43	-	21.0	35.1	39.0	31.7	-	1.7	0.0	3.5	1.7
44	-	39.7	25.8	34.2	33.2	-	2.8	5.6	7.8	5.4
45	11.1	34.6	14.9	19.6	20.0	11.1	11.5	1.8	11.7	9.0
46	23.5	29.9	11.6	21.9	21.7	11.8	11.1	4.1	17.0	11.0
47	15.9	18.4	6.5	33.0	18.4	11.4	21.5	5.2	16.1	13.5
48	0.0	17.0	11.0	45.3	18.3	0.0	19.3	3.0	13.8	9.0
49	12.0	26.4	35.5	44.8	29.7	8.0	19.4	8.4	16.5	13.1
50	12.5	52.6	29.2	21.7	29.0	6.2	11.0	26.1	13.0	14.1
51	-	17.8	34.5	39.7	30.7	-	25.0	14.3	12.5	17.3
52	-	9.1	13.3	38.8	20.4	-	49.1	8.3	13.8	23.7
1	11.1	2.8	17.0	16.3	11.8	11.1	77.5	30.4	34.8	38.4
2	15.4	1.1	28.7	9.2	13.6	50.0	89.7	36.2	52.3	57.0
3	-	1.1	23.5	6.1	10.2	-	23.6	17.6	77.4	39.5
4	0.0	2.4	7.5	6.2	5.4	20.0	52.4	33.9	81.2	46.9
5	13.9	4.7	0.0	3.5	5.5	23.2	90.5	48.6	71.9	58.6
6	5.1	9.7	0.0	0.0	3.7	45.0	81.7	35.7	87.1	62.4
7	14.3	3.4	20.0	14.9	13.1	71.4	91.4	40.0	79.1	70.5
8	25.0	4.4	9.4	16.3	13.8	25.0	89.0	25.0	53.2	48.0
9	0.0	2.0	7.9	16.0	8.6	0.0	81.6	30.7	56.0	56.1
10	-	2.2	0.0	7.7	3.3	-	84.4	9.5	46.1	46.7
11	4.6	18.0	5.0	17.4	11.2	34.8	50.0	15.0	62.8	40.6
12	23.1	9.4	3.1	9.0	11.1	7.7	54.7	12.5	27.8	25.7
13	0.0	19.4	12.5	13.3	11.3	19.0	66.6	12.5	20.0	29.5
14	0.0	6.9	19.0	5.1	7.7	0.0	60.8	35.0	68.4	41.0

Appendix 5 (Continued)

b) Maize

Calendar Week	% Parasitism					% Diseases				
	81-82	82-83	83-84	84-85	Mean	81-82	82-83	83-84	84-85	Mean
49	0.0	0.0			1.0	9.0	0.0			17.2
50	0.0	0.0	3.0	0.0	5.9	5.3	0.0	46.3	0.0	33.9
51	0.0	2.8	14.8	0.0	5.9	44.4	18.6	38.8	0.0	31.6
52	0.0	1.9	7.0	1.1	2.5	10.0	58.5	35.9	21.9	37.2
1	4.3	5.5	0.0	1.6	2.8	6.5	65.1	55.2	21.9	28.2
2	20.4	5.1	8.3	2.2	9.0	9.2	45.3	33.2	25.0	36.8
3	0.0	5.9	4.5	4.2	3.6	13.0	39.8	38.6	55.7	33.3
4	14.5	0.0	0.0	8.5	5.7	16.1	32.7	38.6	45.7	37.6
5	18.2	0.0	0.0	2.4	5.1	22.7	25.7	62.9	39.0	41.5
6	8.4	4.0	0.0	0.0	3.1	30.9	50.0	18.7	66.6	52.7
7	5.1	0.0	0.0	0.0	1.3	13.6	53.0	66.6	77.7	22.8
8	0.0	0.0	0.0	0.0	0.0	4.7	26.9	34.5	25.0	29.7
9	18.2	0.0	5.0	0.0	5.8	64.7	14.3	40.0	0.0	7.4
10	0.0	0.0	0.0	0.0	0.0	15.4	14.3	0.0	0.0	26.7
11	0.0	0.0	0.0	0.0	0.0	50.0	23.5	33.3	0.0	15.5
12	2.0	0.0	0.0	0.0	0.5	24.7	37.5	0.0	0.0	21.5
13	0.7	0.0	10.0	0.0	4.2	30.5	45.4	10.0	0.0	9.1
14	0.0	0.0	5.8	0.0	1.4	21.5	9.1	5.8	0.0	26.5
15	1.3	0.0	0.0	0.0	0.3	36.0	25.0	45.0	0.0	21.0
16	0.0	2.1	4.4	0.0	1.6	34.1	21.3	28.8	0.0	38.2
17	0.0	0.0	1.8	0.0	0.4	17.5	25.0	48.0	62.5	33.8
18	5.0	2.0	0.0	0.0	1.7	31.2	20.0	42.7	41.4	36.0
19	4.3	0.0	0.0	7.4	2.9	13.2	29.0	50.0	51.8	31.5
20	0.0	0.0	0.0	14.3	3.6	33.6	15.2	20.0	57.1	30.1
21	0.0	0.0	0.0	0.0	0.0	45.4	25.0	50.0	0.0	17.9
22	0.0	0.0	0.0	0.0	0.0	28.6	25.0		0.0	

Appendix 5 (Continued)

c) Sorghum

Calendar		% Parasitism					% Diseases				
Week	81-82	82-83	83-84	84-85	Mean	81-82	82-83	83-84	84-85	Mean	
51	35.3				13.1	5.9					
52	15.4	6.7		17.2	13.1	0.0	24.0	16.6	3.4	9.1	
1	52.4	16.7	0.0	29.0	24.5	2.4	35.9		9.7	16.1	
2	38.8	17.0	-	8.5	21.4	7.4	25.7	-	9.6	14.2	
3	21.8	6.2	0.0	2.3	7.6	5.7	35.4	0.0	13.2	13.6	
4	46.2	2.7	0.0	7.5	14.1	3.7	11.1	0.0	11.3	6.5	
5	36.0	0.0	0.0	12.9	12.2	8.0	12.2	0.0	3.2	5.8	
6	33.3	17.8	0.0	10.0	15.3	10.2	23.2	0.0	30.0	15.8	
7	25.0	7.1	0.0	0.0	10.7	4.5	14.3	0.0	44.4	15.8	
8	14.8	5.2	14.3	0.0	8.6	6.9	34.2	0.0	33.3	18.6	
9	25.7	17.6	0.0	0.0	10.8	8.5	0.0	28.5	0.0	9.2	
10	12.1	10.5	0.0	0.0	5.6	8.7	10.5	0.0	0.0	4.8	
11	16.0	13.0	0.0	0.0	7.2	5.7	8.6	0.0	0.0	3.6	
12	15.0	5.0	-	0.0	6.7	15.0	15.0	-	0.0	7.5	
13	16.6	0.0	20.0	0.0	9.1	16.6	14.3	0.0	0.0	10.3	
14	0.0	0.0	0.0		0.0	7.1	0.0	10.0		4.3	
15	0.0	3.2	1.2		1.1	0.0	16.1	0.0		4.0	
16	0.0	7.5	12.8		5.1	0.0	8.6	15.8		6.1	
17	6.5	15.8	10.2		8.1	56.2	14.0	14.6		21.2	
18	0.0	42.8	25.0		16.9	26.6	11.7	5.1		10.8	
19	0.0	9.1	82.3		30.5	22.2	9.1	0.0		10.4	
20	8.0	24.5	0.0		10.8	4.0	18.5	11.7		11.4	
21	29.6	0.0			14.8	20.4	0.0			10.2	

Appendix 5 (Continued)

d) Cotton

Calendar		% Parasitism					% Diseases				
Week	81-82	82-83	83-84	84-85	Mean		81-82	82-83	83-84	84-85	Mean
3		5.9		4.3	5.1			26.7		56.5	41.6
4	0.0	4.3		0.0	1.4		20.0	15.6		0.0	11.8
5	17.6	13.6		8.0	9.8		11.7	20.8	0.0	40.0	18.1
6	27.3	25.7	0.0	0.0	13.2		0.0	14.3	0.0	0.0	3.6
7	25.0	16.6	0.0	0.0	10.4		0.0	15.8	50.0	28.6	23.9
8	8.3	5.9	0.0	3.6	4.4		8.3	18.8	53.5	60.7	35.3
9	0.0	4.4	0.0	0.0	1.1		16.6	9.8	3.5	0.0	7.5
10	6.6	12.4	0.0	0.0	9.7		6.6	12.4	12.5	0.0	7.9
11	3.3	6.1	3.1	0.0	3.1		20.0	12.3	20.2	0.0	13.1
12	0.0	5.3	5.5	0.0	2.2		21.0	10.7	15.5	10.2	14.3
13	0.0	10.5	3.8	4.1	4.6		0.0	3.5	11.5	18.4	8.3
14	0.0	0.0	1.4	0.0	0.3		0.0	23.0	8.7	28.6	15.1
15	0.0	12.1	4.6	0.0	4.2		0.0	12.1	14.3	0.0	6.6
16	0.0	21.6	8.4	27.3	14.3		14.3	13.5	16.1	0.0	10.9
17	0.0	0.0	8.3	5.8	3.5		28.6	40.0	13.6	0.0	20.5
18	9.3	4.1	7.7	0.0	5.3		8.0	28.8	10.0	10.0	12.2
19	3.3	0.0	6.5	20.0	7.4		13.1	16.6	8.7	0.0	9.6
20	12.9	0.0	22.2	0.0	8.8		25.9	0.0	21.7	33.3	20.2
21	22.0	0.0	33.1	11.4	16.6		18.0	0.0	51.9	14.3	21.0
22	10.0	7.0		15.4	10.8		16.6	7.6		7.7	10.6
23	0.0	0.0		22.2	7.3		0.0	0.0		11.1	3.7
24	0.0	0.0					0.0	0.0			

Appendix 5 (Continued)

e) Chickpea

Calendar Week	% Parasitism					% Diseases				
	81-82	82-83	83-84	84-85	Mean	81-82	82-83	83-84	84-85	Mean
18			4.6					5.9		
19			0.0					8.5		
20			1.9					6.9		
21			0.8					8.7		
22		6.0	1.5		3.7		9.1	12.0		11.0
23	0.0	9.2	0.8		3.3	0.0	12.3	21.2		11.2
24	1.2	14.2	3.3	0.0	4.7	20.9	1.2	11.1	0.0	8.3
25	2.8	9.8	5.5	8.1	6.5	7.3	1.4	34.2	12.8	13.9
26	1.2	24.7	4.0	6.7	9.1	5.9	9.1	23.0	18.1	14.0
27	5.2	6.2	0.7	7.0	4.8	6.6	5.4	29.3	14.9	14.0
28	2.4	5.3	0.7	7.9	4.1	5.1	11.6	30.8	11.3	14.7
29	3.3	2.9	13.6	16.3	9.0	12.6	7.3	15.0	5.4	10.1
30	2.9	6.2	5.4	14.7	7.3	4.9	10.1	29.0	15.2	14.8
31	1.5	7.2	5.5	9.9	6.0	2.4	4.8	8.8	11.7	6.9
32	3.5	2.3	0.0	5.0	2.7	13.3	6.4	0.0	29.4	12.3
33	0.9	1.4		2.8	1.7	5.7	8.4		28.7	14.3
34	4.9	1.2		1.8	2.6	5.9	18.3		30.8	18.3
35	3.1	0.0		3.7	2.3	6.4	14.6		10.8	10.6
36	0.0	1.7			.8	0.0	8.4			4.2
37		1.3					7.7			
38		0.0					10.6			
39		0.0					14.7			

Appendix 5 (Continued)

f) Tomatoes

Calendar		% Parasitism					% Diseases				
Week		81-82	82-83	83-84	84-85	Mean	81-82	82-83	83-84	84-85	Mean
40		2.4	10.0	0.0	0.0	3.1	45.2	40.0	0.0	0.0	21.3
41		7.0	2.9	0.0	0.0	2.5	41.2	14.7	7.6	0.0	15.9
42		6.1	22.2	6.2	0.0	8.6	63.6	16.6	6.2	0.0	21.6
43		0.0	9.1	7.6	0.0	5.6	0.0	0.0	7.6	0.0	2.5
44		0.0	0.0	30.0	0.0	7.5	67.7	25.0	5.0	0.0	24.4
45		16.7	33.3	20.7	-	17.7	66.7	50.0	1.7	-	29.6
46		0.0	31.6	0.0	-	7.9	50.0	10.5	9.3	-	17.4
47		0.0	20.0	9.1	-	9.7	0.0	20.0	9.1	-	9.7
48			0.0	0.0	-	0.0	0.0	0.0	0.0	-	0.0
49			25.0	0.0	-	12.5	0.0	0.0	0.0	-	0.0
50			0.0	17.4	-	8.7	0.0	0.0	21.7	-	10.8
51			0.0	10.2	-	5.1	0.0	0.0	11.1	-	5.5
52			0.0	13.4	-	6.7	0.0	0.0	15.8	-	7.9
1			0.0	8.8	0.0	2.9	25.0	25.0	24.4	6.0	18.5
2			5.8	5.5	0.0	3.7	29.4	29.4	11.1	0.0	13.5
3					2.8					40.9	
4					6.7					24.0	
5					0.0					25.0	
6					8.3					83.3	
7					18.5					40.7	
8					0.0					66.6	
9					14.3					28.6	

Appendix 6. Comparison of H. armigera weekly total moth catches in different trap designs and colours at Ukiriguru in 1982: Weekly moth catch transformed to Log (X+10). Summary of statistical analysis.

a) Mbuga field site

i. Moths caught from week 8 to 25

ANOVA table

Source of variation	df	SS	MS	F-ratio
Total	54	2.2445		
Traps	2	0.0157	0.0078	0.4243 n.s.
Weeks of trapping	17	1.5989	0.0940	5.0839***
Error	34	0.6299	0.0185	

ii. Moths caught from week 8 to 16

ANOVA table

Source of variation	df	SS	MS	F-ratio
Total	35	1.7872		
Traps	3	0.3143	0.1047	4.2075*
Weeks of trapping	8	0.8748	0.1093	4.3915**
Error	24	0.5981	0.0249	

iii. Moths caught from week 17 to 25

ANOVA table

Source of variation	df	SS	MS	F-ratio
Total	26	0.3463		
Traps	2	0.0356	0.0178	1.8541 n.s.
Weeks of trapping	8	0.1559	0.0195	2.0299 n.s.
Error	16	0.1548	0.0096	

b) Machafu field site

i. Moths caught from week 5 to 8

ANOVA table

Source of variation	df	SS	MS	F-ratio
Total	31	1.4170		
Traps	3	0.7230	0.2410	14.0935*****
Weeks of trapping	7	0.3343	0.0477	2.7928*
Error	21	0.3597	0.0171	

Appendix 6 (continued)

b) Machafu field site (continued)

ii. Moths caught from week 9 to 12

ANOVA table

Source of variation	df	SS	MS	F-ratio
Total	19	1.0905		
Traps	4	0.7261	0.1815	13.5466****
Weeks of trapping	3	0.2039	0.0679	5.0720*
Error	12	0.1605	0.0134	

iii. Comparison of EL-Dieb and Ukiriguru traps: Moths caught from week 13 to 25: Summary of a paired t-test

	EL-Dieb trap	Ukiriguru trap
Weeks of observation	13	13
Total number of moths (Σx)	14.17	15.44
Mean catch/week (\bar{x})	1.09	1.18
Σx^2	15.686	18.498

$$\text{Pooled } S^2 = \frac{1}{24} \left(15.686 - \frac{14.17^2}{13} + 18.498 - \frac{15.44^2}{13} \right)$$

$$S^2 = 0.01669$$

$$S = 0.1292$$

$$t = \frac{13}{0.1292 \sqrt{\frac{1}{13} + \frac{1}{13}}}$$

$$t = 256.4952**** \text{ with 24 degrees of freedom}$$

n.s. = statistically not significant

* = statistically significant at $P < 0.05$

** = statistically significant at $P < 0.01$

*** = statistically significant at $P < 0.005$

**** = statistically significant at $P < 0.001$

Appendix 7 Summary of H. armigera moth catches in pheromone traps at Ukiriguru from April to July 1982:

Comparison of white and yellow painted Ukiriguru trap design presented as weekly total of number

of moths caught

Calendar Week	Nolle		Mwinyi		Nyashimba		Mbuga		Machafu	
	White	Yellow	White	Yellow	White	Yellow	White	Yellow	White	Yellow
13	22	29	19	42	20	34	17	12	9	9
14	40	20	13	22	27	19	6	11	11	11
15	3	6	4	8	3	19	4	3	5	5
16	5	3	2	6	5	10	1	1	3	3
17	14	4	1	4	12	6	2	7	0	0
18	3	7	9	6	4	12	4	4	3	3
19	11	4	9	3	11	10	6	7	1	1
20	12	5	7	4	14	13	11	0	5	5
21	3	4	4	4	8	11	2	0	9	9
22	0	2	5	11	4	18	0	0	4	4
23	8	4	6	28	1	53	9	6	15	15
24	11	14	8	14	5	48	4	0	9	9
25	10	13	11	26	23	36	9	2	2	2
26	9	13	6	22	28	35	5	0	6	6
27	1	0	2	11	9	14	0	1	0	0
28	4	1	1	6	1	12	0	0	0	0
29	0	1	1	1	5	4	1	2	1	1
Total	156	130	108	218	179	354	81	56	83	83
Mean catch per week	9.17	7.65	6.35	12.82	10.53	20.82	4.76	3.29	4.88	4.88

Appendix 8. Comparison of the weekly number of moths caught in the white and yellow coloured Ukiriguru traps: summary of a paired t-test analysis.

	White trap	Yellow trap
Weeks of observation	17	17
Total number of moths (Σx)	524	758
Mean catch per week (\bar{x})	30.8	44.6
Σx^2	25436	50220

$$\text{Pooled } S^2 = \frac{1}{32} \left(25436 - \frac{524^2}{17} + 50220 - \frac{758^2}{17} \right)$$

$$S^2 = 803.330$$

$$S = 28.343$$

$$t = \frac{17}{28.343 \sqrt{\frac{1}{17} + \frac{1}{17}}} = \frac{17}{9.7215} = 1.7487 \text{ n.s. with 32 degrees of freedom}$$

Appendix 9. Comparison of moth catches at different sites in Ukiriguru
research station April - July 1982: Summary of analysis of
variance

ANOVA table

Source of variation	df	SS	MS	F-ratio
Total	67	19279.221		
Trapping sites	3	4730.397	1576.6666	19.8643*****
Weeks of trapping	16	10738.971	671.1857	8.4562***
Error	48	3809.853	79.3719	

*** = statistically significant at $P < 0.01$

**** = statistically significant at $P < 0.001$

Appendix 10. Comparison of site differences in the number of moths caught per week at Mabuki cotton seed multiplication farm in 1982. Summary of paired t-test analysis

	Shamba No. <u>1</u>	Shamba No. <u>6</u>
Weeks of observation	22	22
Total Number of moths caught (Σx)	958	604
Mean catch per week (\bar{x})	43.5	27.4
Σx^2	75474	26046

$$\text{Pooled } S^2 = \frac{1}{42} \left(75474 - \frac{958^2}{22} + 26046 - \frac{604^2}{22} \right)$$

$$S^2 = 1029.069$$

$$S = 32.079$$

$$t = \frac{22}{32.079 \sqrt{\frac{1}{22} + \frac{1}{22}}}$$

$$t = 2.2745^* \text{ with 42 degrees of freedom, } P < 0.05$$

Appendix 11.

- a) Summary of statistical analysis of the trap placement height in the cotton crop during 1983: The data was transformed to Log (X+10)

ANOVA table

Source of variance	df	SS	MS	F-ratio
Total	154	0.7399		
Trap heights	4	0.0052	0.0013	0.6842 n.s.
Days of trapping	30	0.5037	0.0168	8.8368 ****
Error	120	0.231	0.0019	

$$\text{Standard error} = \sqrt{\frac{\text{EMS}}{31}} = \pm 0.0078$$

Trap heights above the crop canopy

	30cm	60cm	80cm	90cm	100cm	
Mean catch per day	1.04	1.04	1.05	1.04	1.04	±0.008

- b) Analysis of variance based on total catch of not less than 5 moths per night : Data selected from Table 22 and transformed to Log (X+10)

Trap heights above the crop canopy

Date	30cm	60cm	80cm	90cm	100cm
1	1.00	1.04	1.08	1.00	1.08
2	1.00	1.04	1.08	1.08	1.11
3	1.08	1.04	1.04	1.00	1.14
4	1.08	1.00	1.11	1.11	1.08
5	1.04	1.00	1.14	1.04	1.00
6	1.25	1.14	1.20	1.34	1.14
7	1.00	1.08	1.00	1.00	1.11
8	1.00	1.00	1.11	1.04	1.04
9	1.14	1.11	1.14	1.17	1.08
10	1.45	1.20	1.25	1.23	1.14
11	1.08	1.08	1.11	1.00	1.08
12	1.00	1.17	1.08	1.11	1.00
13	1.00	1.11	1.00	1.00	1.08
Total	14.12	14.01	14.34	14.12	14.08
Mean catch per night	1.08	1.08	1.10	1.08	1.08 ± 0.017

Appendix 11 (Continued)

Summary of the analysis of variance

ANOVA table

Source of variance	df	SS	MS	F-ratio
Total	64	0.4877		
Trap heights	4	0.0047	0.00117	0.3012 n.s.
Days of trapping	12	0.2947	0.0245	6.2970****
Error	48	0.1883	0.0039	

n.s. = statistically not significant

**** = statistically significant at $P < 0.001$

Appendix 12. Summary of analysis of variance of the trap placement height in the chickpea crop : The data was transformed to $\text{Log}(X+10)$

ANOVA table

Source of variance	df	SS	MS	F-ratio
Total	123	0.1907		
Trap heights	3	0.0243	0.0081	6.8322****
Days of trapping	30	0.0597	0.0019	1.6785*
Error	90	0.1067	0.0011	

$$\text{Standard error} = \sqrt{\frac{\text{EMS}}{31}} = \pm .006$$

Trap height above plant canopy

	0cm	25cm	75cm	125cm
Mean catch per day	1.02	1.05	1.02	1.01 ± 0.006

* statistically significant at $P < 0.05$

**** statistically significant at $P < 0.001$

Appendix 13. Record sheet specimen

Weeks	TREATMENT				
	Date	Egg/Plant	Larvae/Plant	Flares/Plant	Spray Date
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					

Appendix 13b. Pest Counts

Trial No.....Site.....Treatment.....Date.....

Plot No.	Plant	Heliothis Eggs/Larvae	Earias Larvae	Jassid Grades 0-4	Dysdercus Adults/ Nymphs	Calidea Adults	Aphids Grades 0-4	RSM Grades 0-4	Helopeltis Grades 0-4	Lygus Grades 0-4	Other Pests and Remarks
	1										
	2										
	3										
	4										
	5										
	Total										
	1										
	2										
	3										
	4										
	5										
	Total										
	1										
	2										
	3										
	4										
	5										
	Total										
	1										
	2										
	3										
	4										
	5										
	Total										
	TOTAL										
	MEAN										

Appendix 14a: Spraying threshold guide

a) Number of eggs or larvae per plant from the total found on 25 plants

Total eggs and larvae per 25 plants	Eggs and larvae per plant	Total eggs and larvae per plant	Eggs and larvae per plant
1	0.04	31	1.24
2	0.08	32	1.28
3	0.12	33	1.32
4	0.16	34	1.36
5	0.20	35	1.40
6	0.24	36	1.44
7	0.28	37	1.48
8	0.32	38	1.52
9	0.36	39	1.56
10	0.40	40	1.60
11	0.44	41	1.64
12	0.48	42	1.68
13	0.52	43	1.72
14	0.56	44	1.76
15	0.60	45	1.80
16	0.64	46	1.84
17	0.68	47	1.88
18	0.72	48	1.92
19	0.76	49	1.96
20	0.80	50	2.00
21	0.84	51	2.04
22	0.88	52	2.08
23	0.92	53	2.12
24	0.96	54	2.16
25	1.00	55	2.20
26	1.04	56	2.24
27	1.08	57	2.28
28	1.12	58	2.32
29	1.16	59	2.36
30	1.20	60	2.40

Appendix 14b.

Number of bollworm damaged flared buds and flowers
from the total found on 50 plants

Total flared squares per 50 plants	Flared squares per plant	Total flared squares per 50 plants	Flared squares per plant	Total flared squares per 50 plants	Flared squares per plant
1	0.02	31	0.62	61	1.22
2	0.04	32	0.64	62	1.24
3	0.06	33	0.66	63	1.26
4	0.08	34	0.68	64	1.28
5	0.10	35	0.70	65	1.30
6	0.12	36	0.72	66	1.32
7	0.14	37	0.74	67	1.34
8	0.16	38	0.76	68	1.36
9	0.18	39	0.78	69	1.38
10	0.20	40	0.80	70	1.40
11	0.22	41	0.82	71	1.42
12	0.24	42	0.84	72	1.44
13	0.26	43	0.86	73	1.46
14	0.28	44	0.88	74	1.48
15	0.30	45	0.90	75	1.50
16	0.32	46	0.92	76	1.52
17	0.34	47	0.94	77	1.54
18	0.36	48	0.96	78	1.56
19	0.38	49	0.98	79	1.58
20	0.40	50	1.00	80	1.60
21	0.42	51	1.02	81	1.62
22	0.44	52	1.04	82	1.64
23	0.46	53	1.06	83	1.66
24	0.48	54	1.08	84	1.68
25	0.50	55	1.10	85	1.70
26	0.52	56	1.12	86	1.72
27	0.54	57	1.14	87	1.74
28	0.56	58	1.16	88	1.76
29	0.58	59	1.18	89	1.78
30	0.60	60	1.20	90	1.80

